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Adaptive Simulation of an Integrated Procurement-Inventory System with Incomplete Lead Time Information

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ADAPTIVE SIMULATION OF AN INTEGRATED PROCUREMENT-INVENTORY SYSTEM WITH INCOMPLETE LEAD TIME INFORMATION

by

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ABSTRACT

The functions of procurement, inventory control and warehousing are shown to be an integrated system which requires consideration of the costs of all the related functions in order to specify a policy which has a minimum total cost for a desired level of service. A stochastic environment is assumed in which a Poisson distributed demand is known and initially only an estimate of the average lead time is available for each vendor. An adaptive model is developed which specifies a policy using a dynamic programming algorithm and then simulates one year's activity utilizing the policy. Policies in succeeding years are based on increased information of lead time distribution from previous years of simulation.

Two modes of operation based on an effective service level are defined: a fixed mode in which effective service level is the same as the desired service level and an adaptive mode in which the effective service level is altered according to information obtained from the simulation.

An investigation with the model is performed and it is concluded that reasonably good service levels can be attained when lead time information is restricted to estimates of the average, a stable vendor selection will usually occur in the period of interest, and the fixed service level mode provides a higher level of service while the adaptive service level mode provides acceptible service levels at lower cost.

CHAPTER I

INTRODUCTION

The modern industrial organization has a steadily increasing involvement with computer based systems for performance of repetitive tasks, control of operations and provision of information for management decisions. A chief concern of management science is the development of methods to quantify the management decision process so that more decisions can be performed by the automatic rather than the human elements of the system. Some of the generally held advantages of this automation are:

1. Relieving managers of time consuming routine decision making so that they can devote more effort to activities such as development and evaluation of methods and personnel.
2. Improvement in the quality of decisions according to standards such as uniformity, timeliness, and optimality.
3. Integration of the decision making process so that the goals of the entire organization are best served rather than the goals of individual managers or departments.

Inventory control has been a favorite field for management scientists and many types of inventory decisions are now routinely performed by a computer which at one time required a skilled analyst. However, the inventory system and other systems are in reality interdependent, which implies that the integration of systems would be worthwhile. This thesis deals with an integrated procurement-inventory system.

A. Concepts

An almost innumerable variety of items are procured from outside sources by manufacturing companies. These items may be required for processing into the finished product, for an intermediate step in a process like etching or cleaning, for packaging the finished product, or for a supporting function such as maintenance, production control, engineering or accounting. A substantial portion of direct costs are usually attributed to procured material, and further costs are incurred by inventories of this material which are carried as a protection from shortages that would impede the progress of manufacture. Thus the proper management of procurement is essential for an efficient and profitable manufacturing operation.

Most companies divide the responsibility for procurement so that no individual or group is responsible for the total task. The division arises from natural sub-tasks that occur in the chain of procurement events which begin with an identified need for an item and end with the provision of the item to the user. A typical division of responsibility is:

Engineering

Purchasing

Production and Inventory Control

Warehousing

User

In this arrangement, the product or design engineer provides a specification for the product which includes selection of raw materials and components. The purchasing group then is responsible for contacting the vendors, requesting bids and analyzing these bids for the lowest price consistent with quality, and other somewhat intangible factors such as reputation for reliable delivery. Based on this analysis, the purchasing group selects a vendor or vendors from which to purchase the product.

The production and inventory control group in the manufacturing center places orders with the selected vendors as required. This group is also responsible for the costs of inventory and ordering.

When material arrives at the factory, the warehousing organization arranges for storage and supplies the shop or other user with increments as directed by production and inventory control. Efficient handling of the material and provision at the proper location and time falls within the responsibility of the warehousing organization. The group utilizing the purchased product assumes the responsibility of efficient use and feedback on quality as with any other resource.

From an operating viewpoint, the division of the procurement task is obvious. Since the type of skill and experience for each group is different, the company benefits from specialization in the work force. Since the duties of each group are well defined, the company benefits from clearcut managerial responsibility for setting policy, achieving results and control of specific costs. However, from a broader viewpoint this division of responsibility results in inefficiencies since the goals of each group are different and the activities of one group may impinge upon the activities carried out in the other groups.

An example of this interaction is the order quantity. A minimum order quantity (MOQ) may be a part of the vendor's quotation and generally the unit price is lower for a larger MOQ. Thus, other factors being equal, the purchasing organization tends to select a vendor with a larger MOQ in order to reduce unit costs.

On the other hand, inventory control determines an economic order quantity (EOQ) by considering the opportunity costs of holding inventory, the cost of placing an order and vendor's setup costs, in addition to the item costs. If the vendor selected by purchasing has a MOQ greater than the EOQ there is a clear conflict in the policies of purchasing and inventory control.

Resolution of this conflict may also involve the warehousing organization. Warehousing has a limited amount of space, equipment and personnel to handle incoming material. Either the MOQ or EOQ may be inappropriate from this viewpoint, since peak storage requirements may either exceed the warehousing resources or cause increased costs due to inefficient storage arrangements and overtime payments to hourly employees.

Further inspection of the procurement process indicates more interaction between purchasing, inventory and production control and warehousing. Vendor selection affects the lead time between order placement and delivery which in turn affects the reorder point used by inventory control. The variation in lead time affects the amount of safety stock carried in the inventory which is of concern to both inventory control and warehousing.

Thus it may be concluded that purchasing, production and inventory control, and warehousing must be considered as an integral unit in regard to procurement policy. Hence the optimal policy will be determined by minimizing the total costs incurred by vendor selection, ordering policy and warehousing.

It is also apparent that while the engineering and user organizations affect the total procurement costs, in specifying and utilizing the product, these organizations are not an integral part of the procurement system. A change in specifications requires reevaluatien of the procurement policy, but the alternatives in specifications are evaluated by more extensive criteria than item, inventory and warehousing costs. Similarly a change in the efficiency of utilization will be reflected in the distribution of demand, but methods of obtaining increased efficiency include many factors in addition to procurement.

Controlling these components of procurement cost are properly problems in value engineering and quality control. However, a method of obtaining an optimal policy within the integral procurement unit would be a valuable tool for analyzing engineering and quality problems. For instance, an engineer considering a quality change would be able to evaluate the impact of the change upon procurement cost.

B. Methods

Consider a common situation in sizable industrial concern which makes the procurement function quite complicated: -

1. A large number of items must be procured from many possible vendors.
2. There is competition among these items for a limited warehouse space.
3. Demand and vendor's lead time are stochastic.
4. Management requires a certain level of service.

Determination of minimum procurement cost is clearly beyond simple pencil and paper solutions. A sophisticated model is required which utilizes the memory and computational power of the digital computer.

This problem has been considered in some detail by W. J. Fabrycky and J. Banks.[1] The term MIMS, for a multiple-item-multiple-source system, is coined by them as a generic term for an integrated procurement and inventory system. Dynamic programming is advanced as an optimal solution technique and is shown to give reasonably close answers to the method of Lagrangian multipliers when applied to simpler systems with single items or single sources.

P. T. Lele and E. A. Siecienski[2] have adapted the dynamic programming technique to a MIMS system with refinements of the cost equation to consider material which does <u>not</u> have warehousing costs proportional to unit costs, as is usually assumed, and rental costs which are a function of the space utilization in the warehouse. Lele and Siecienski also specifically related the MIMS system to the concept of avoiding suboptimization due to the division of managerial responsibility.

The MIMS system of Fabrycky and Banks was basically deterministic with the provision that expected values could be substituted for exact values when such a scheme was satisfactory to the user.
J. L. Kingsley[3] has built upon the deterministic model of Lele and Siecienski, using expected values, but explicitly specifying the stochastic parameters of the cost equations and introducing the constraint of the minimum level of service required by management.

Kingsley included a method, based on generating functions, for convoluting discrete probability distributions of demand and lead time. This convolution is required to compute the distribution of demand during lead time for modeling the stochastic inventory system. In the real world, demand and lead time are often empirical distributions which cannot be convoluted by textbook methods.

To the author's knowledge, this is the most refined model available for optimizing a MIMS system. The chief limitation, as with any application of dynamic programming, is the large memory and process time required for solution of systems with a great number of units and sources. To some extent, this limitation can be avoided by first grouping related items and then applying the model to each group. However, in a situation where all items are competing for warehouse space, this method of decomposition may not be optimal.

Other mathematical programming techniques could be applied to the MIMS system, but are less powerful than dynamic programming.

M. Schrader[4] has applied linear programming to quotation analysis, but as we have shown, this is suboptimization of the integrated procurement system. Fabrycky and Banks also apply linear programming to a MIMS system, but in the context of continuous flows of material without holding inventory. Linear programming is also restricted since integer variables such as setup costs and unit orders cannot be properly treated.

It is theoretically possible to apply integer programming to the deterministic MIMS problem. However, it should be observed that integer programming formulations are too large because of the presence of many integer variables and the addition of many integer constraints to be solved by currently available computer algorithms. In the MIMS system, the MOQ for each vendor and each item is a constraint and all variables except for costs are integer. Extension of integer programming to the stochastic MIMS system where the stochastic variables had untabulated distributions is another and perhaps the most difficult problem for this approach.

Simulation is often used when real data is unavailable, the system is so complex that analysic solutions are difficult, or when designed experiments on the real system are either prohibitively expensive or perilous to the system's operation. Simulation also offers a useful verification of analytic solution procedures, as Fabrycky and Banks show for a single-item-multiple-source system.

A more recent trend, as noted by J. B. Boulden[5]. is the use of optimization models as a complement rather than as a competitor to simulation models. In this manner, the optimization model can define the problem and interact with the simulation model which provides data on which to base optimal policies or tests the optimal policies in a stochastic environment. When an optimization model is available, this approach should greatly reduce the effort in designing and programming a simulator.

A potential application of this type of interactive model is in simulations where a planning phase would exist in the real world which cannot be satisfactorily represented by random variables or simple rules. The MIMS system is well suited to this approach since optimal models are available and procurement planning is sufficiently complex.

C. Scope

In his analysis, Kingsley assumed that a discrete probability distribution of lead times could be obtained from the vendor. While this assumption may be often correct, it is believed that an estimate of the average lead time is the maximum information that will be available from many vendors. In these cases, the initial procurement policy would have to be based upon the lead time estimates. Succeeding policies would then be based upon a mixture of estimates and empirical distributions of lead times for those vendors who have been previously selected.

Thus there is a dynamic region of procurement policies based upon increasing information of the vendor's lead time until sufficient information has been obtained to ensure a consistent policy, providing that the underlying distributions of lead times and other pertinent factors do not vary with time. This dynamic region is investigated in this thesis by interactive application of a modified version of the Kingsley's procurement model and a simulation of stochastic demands and lead times with back ordering of unfilled demands.

To facilitate the investigation, the optimal procurement model and the simulator have been structured into a single model which formulates a procurement policy and then simulates one year's activity. Interactive reformulation of policy based upon the previously simulated data, and another year's simulation can be performed as desired.

It will be shown that modification of the Kingsley procurement model is required to provide sensitivity to the information about the vendor's lead time supplied by the simulation. The service level will be redefined and a mode of operating the model which is adaptive to the service level will be developed.

It should be noted that several factors can be added to the MIMS system which will not be considered here. Among these are demand forecasting, alternatives in warehouse investment, decisions to make or buy products, and quantity constraints on individual sources of supply. The assumption will be made that the stochastic demand is stationary with a known distribution, that sufficient warehouse space is available for the quantity used during a lead time plus safety stock, that a decision has been made to purchase the product, and that each vendor can supply the required quantities. Although these assumptions preclude investigation of some interesting aspects of the system, great simplification is obtained which will aid investigation of the desired area.

In the investigation, iterations will be performed for a 20 year horizon which is considered the maximum length of interest for a stationary demand. Stability will be measured by consistent selection of the same vendor. It is desired to find the period required for stability under this criteria for various conditions and to find the associated characteristics of cost and service level.

CHAPTER II

THE ADAPTIVE MODEL

A. Overview

Since it is anticipated that the procurement policy will be altered to correspond to increased information about the vendor as iterations are performed, this model may be termed adaptive as well as interactive. The term adaptive is really more appropriate to this investigation since a major point is the change in policy with the change in information. Hence the phrase adaptive model will be adopted.

Figure 1 is a simplified block diagram of the model, which is introduced at this point to provide an over-all view prior to the detailed description in the following sections.

It will be noted that the terms procurement planning submodel and simulation submodel are used to describe the major modules of the model in Figure 1. These terms are introduced to avoid confusion when the word model is used.

B. System Definition

A clearer understanding of the adaptive model can be obtained by first defining the operating procedures in the procurement system under consideration. The following conditions are assumed to prevail.

1. A single vendor is selected on a competitive basis for each purchased item.
2. Vendors are awarded annual contracts in order to assure the desired source of supply.

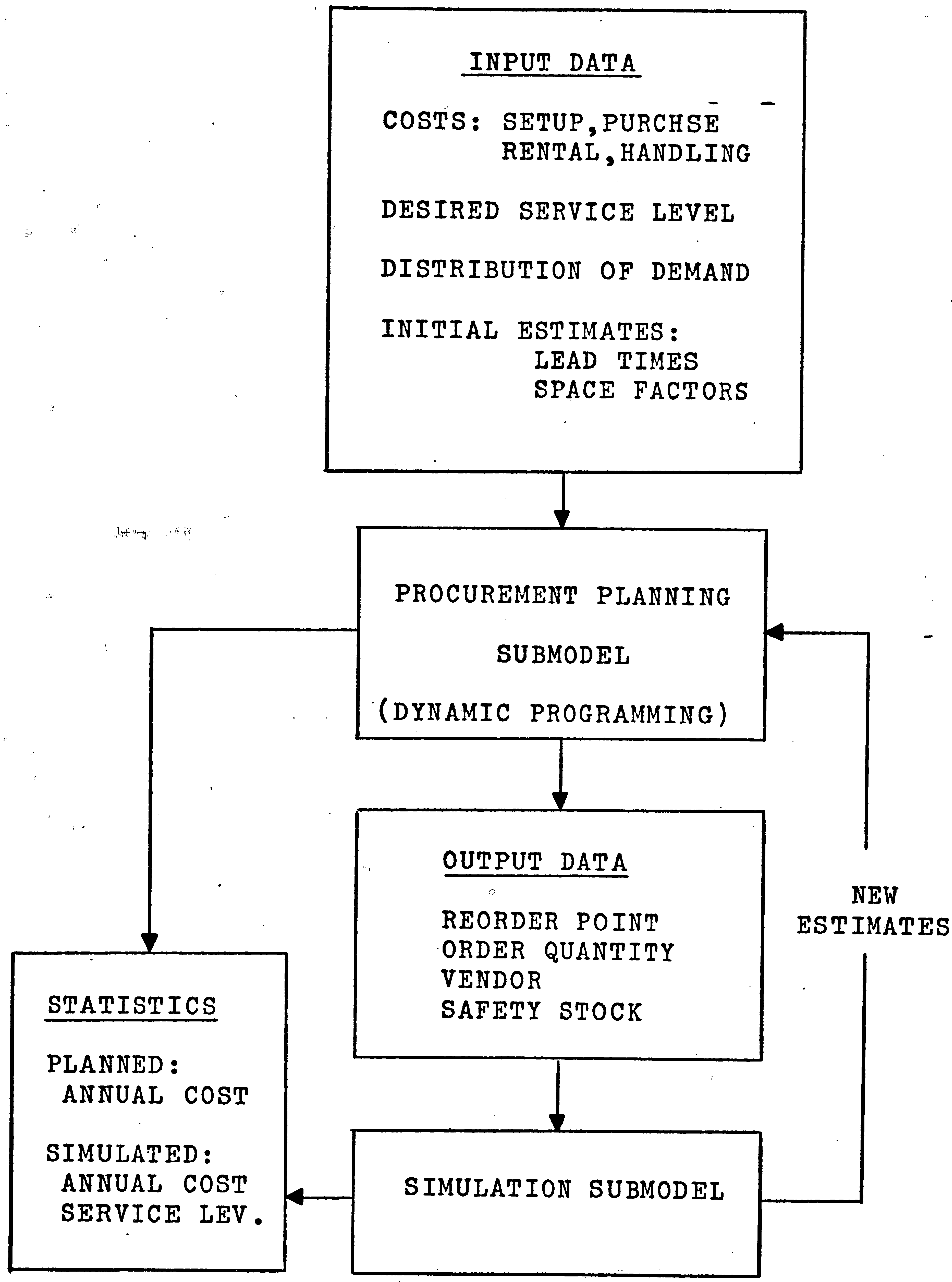


FIGURE 1 - SIMPLIFIED DIAGRAM OF THE ADAPTIVE MODEL

3. All orders, deliveries and withdrawals are made in increments of full pallet loads.
4. An entire order is delivered at one time.
5. Records for orders, deliveries and withdrawals are updated once each business day with 250 such days representing one year.
6. The inventory level is checked against the reorder point and orders are initiated, if necessary, for each item as the records are updated.
7. Demands are filled from the next delivery when the quantity on hand is insufficient.
8. Safety stocks are either stored separately from other stocks in the least accessible sections of the warehouse or in a separate warehouse.

The specific implication of these assumptions will be brought out as the adaptive model is described. In general, it can be seen that a mechanized warehouse arrangement is envisioned that will only accept pallet loads and consequently the pallets are broken down and depleted in the users area. For purposes of procurement planning and simulation, transactions will be conducted in terms of pallets even though many units of material would be contained in one pallet load.

A manufacturing organization following these procedures would undoubtedly require a business system to record transactions and to initiate orders. However, it is felt that the purpose and definition of the business system is much broader in scope than the procurement system. Therefore, the cost of the business system will not be considered in the analysis, since the recording of transactions is also required for other purposes such as accounting, and there is little controllable cost directly attributable to the method of procurement.

C. Procurement Planning Submodel

The detailed development of a procurement model is included in Kingsley's thesis.[3] For our purposes, it is sufficent to describe the input-output variables, pertinent features of operation and modifications made by the author to suit an adaptive application.

Consider that I items must be procured and that there are V vendors who may bid on any or all items. Let the subscript i (i = 1, 2, 3,..., I) designate ith item and the subscript v (v=1, 2, 3, ..., V) represent vth vendor. Then the following glossary lists the notations used in the model.

Glossary

Notation	Definition
A	Coefficient of exponential smoothing used for parameters which are adjusted by information from the simulation.
ALPHA	Space utilization factor for regular stock.
BETA	Minimum percent of demands which management requires to be filled from inventory (service level).
C_{iv}	Cost per pallet for item i when ordered from vendor v.

Notation	Definition
DELTA	Space utilization factor for safety stock.
D_i	Expected annual demand for item i.
E	Coefficent used in adaptive beta mode.
F	Fixed cost incurred within the company each time an order is placed.
H	Handling cost to either store or withdraw a pallet of regular stock.
H_{ss}	Handling cost to either store or withdraw a pallet of safety stock.
h(x)	Probability of x pallets being demanded during a lead time.
M_{iv}	Minimum order quantity for item i when ordered from vendor v ($M_{iv} \geq 0$) (Denoted by MOQ in Chapter I).
O	Overstock cost per pallet charged when delivery causes the stock on hand to exceed the planned capacity of the warehouse.
P	Annual cost of a regular pallet position in the warehouse, exlusive of handling cost.
P_{ss}	Annual cost of a pallet position of safety stock in the warehouse, exlcusive of handling cost.

Notation	Definition
$Pr(x_i)$	Probability of x pallets (x = 0, 1, 2, 3, ...) of item i being demanded on any day.
$Pr(t_{iv})$	Probability of t days (t = 1, 2, 3, ...) being required for delivery after an order for item i is placed with vendor v.
q_{iv}	Order quantity for item i when ordered from vendor v.
$Q(q_{iv})$	The expected annual procurement cost corresponding to order quantiy, q_{iv}.
R	Percent return on investment required by company policy.
r_{iv}	Reorder point in pallets for item i when ordered from vendor v.
S_{iv}	Setup cost charged by vendor v for each order of item i.
ss_{iv}	Number of pallets of safety stock required when item i is obtained from vendor v.
T_i	Probability of an overstock when an order of item i is received.
$TC(w_I)$	Total expected cost for warehouse size w_I.
u_i	Equivalent space allocated to item i at each state of the dynamic programming algorithm.

Notation	Description
$Y_i(u_i)$	Minimum expected cost procurement policy given space u_i is available for item i.
z_{iv}	Demand for item i during a lead time when ordered from vendor v. (A Random Variable)
$\bar{z}_{iv}$	Expected value of z_{iv}.

The Pr(x) and $Pr(t_{iv})$ are convoluted by means of generating functions for all i and v to find $Pr(z_{iv})$, where z_{iv} is the random variable describing usage during lead time. Then r_{iv}, the reorder point for procuring item i from vendor v is defined by the relation:

$$Pr(z_{iv} > r_{iv}) \leq 1 - BETA \qquad - (1)$$

Where r_{iv} is an integer number of pallets.

Let $\bar{z}_{iv}$ be the expected value of z_{iv} and ss_{iv} be the number of pallets of safety stock required if item i were to be obtained from vendor v. As shown above r_{iv} was set with respect to BETA, the percent of demands to be filled from inventory, and on the average only $\bar{z}_{iv}$ will be consumed during a lead time. Therefore, we may calculate ss_{iv} by:

$$ss_{iv} = [r_{iv} - \bar{z}_{iv}]^{+} \qquad (2)$$

where $[\ ]^{+}$ indicates rounding up to an integer.

Rounding is required in this expression as ss_{iv} and r_{iv} are integers, but $\bar{z}_{iv}$ is a positive real number. Rounding up is used because this gives a more conservative figure for the safety stock. It should be noted that rounding up places a lower bound of one pallet on the amount of safety stock, another conservative measure.

Now let q_{iv} be the quantity of item i to be ordered from vendor v.

Then $Q(q_{iv})$, the expected annual procurement cost for q_{iv}, can be written as the sum of the following annual costs.

$$\text{Purchasing} = C_{iv} \cdot D_i \tag{3a}$$

$$\text{Ordering} = \frac{D_i}{q_{iv}}(F + S_{iv}) \tag{3b}$$

$$\text{Opportunity} = R \cdot C_{iv}((q_{iv})/2 + ss_{iv}) \tag{3c}$$

$$\text{Shortage} = \frac{\Pi_i C_{iv}}{D_i} \sum_{x=r_{iv}}^{\infty} x \cdot h(x) \tag{3d}$$

where Π_i is the implied cost of a stock out from setting BETA, the minimum percent of demands to be filled from inventory, and $h(x)$ represents the probability of x pallets being demanded during a lead time.

$$\text{Overstock} = \frac{O \cdot D_i}{q_{iv}} \cdot T_i \tag{3e}$$

$$\text{Safety stock space rental} = (P_{ss} \cdot ss_{iv})/\text{DELTA} \tag{3f}$$

$$\text{Safety stock handling} = \frac{2 \cdot H_{ss} \cdot D_i}{q_{iv}} \sum_{x=L_{iv}}^{r_{iv}} (x - L_{iv}) h(x) \tag{3g}$$

$$\text{where } L_{iv} = r_{iv} - ss_{iv}$$

It will be noted that equations 3a, 3b, and 3c are similar to those found in the familar Wilson model. Equation 3d, the shortage cost, is derived by Kingsley,[3] and is similar to methods used by Hadley and Whitin [7] The remaining equations, representing the overstock, safety stock rental, and safety stock handling costs, require further explanation.

In equation 3c, the overstock cost O is a one time charge representing labor and co-ordination costs to work around a bottleneck caused by a delivery which combined with the stock on hand exceeds the planned capacity of the warehouse. The term (D_i/q_{iv}) is the number of deliveries per year of item i from vendor v and T_i is the probability of an overstock when a delivery of item i is made. In the adaptive model, estimates of T_i can be obtained from the simulation data. The method used is, therefore, to provide an initial estimate of T_i and to compute the percentage of overstock occurring in the simulation of a year's transactions. The new estimate of T_i is obtained by using exponential smoothing to reduce the effect of variance in the simulation. This expression is:

$$(T_i)_{new} = (T_i)_{old} \cdot (1-A) + (\text{PERCENT OVERSTOCK}) \cdot A \qquad (4)$$

$$\text{where } 0 < A < 1,\ 0 \leq T \leq 1$$

Equations 3f and 3g are the expected annual space rental and handling costs for the safety stocks. The space rental and handling costs for the regular stocks are not represented in equations 3f through 3g. Since these costs are not functions of q_{iv}, they are added to the total cost after a vendor is selected for each feasible quantity by the dynamic programming algorithm.

The space rental cost for the safety stock also is not a function of q_{iv} and originally was included at the same point as the regular stock rental cost. However, the safety stock requirement is a function of v and in particular a function of the vendor's lead time distribution. In general, large lead time variances are undesirable and should be discriminated against by the associated costs of which the safety stock rental is a major part.

Preliminary runs made in the development of the adaptive model, indicated that the procurement submodel was not sensitive to variance in vendor's lead times. In a sample case, hand calculations indicated that the vendor selected by the model had a higher total cost than other vendors who had smaller safety stock requirements. When the safety stock was reformulated as a part of $Q(q_{iv})$ vendor selection agreed with hand calculations and a general improvement of sensitivity to lead time variance was observed.

It will be noted that the safety stock rental contains a variable DELTA in the denominator. DELTA represents the space utilization in the safety stock area or warehouse and will be explained later. In many analyses, the cost of handling the safety stock is lumped with the regular stock handling cost. This was found to be a poor approximation when the safety stock has a higher handling cost than regular stock due to inaccessible storage location as has been assumed in this investigation. The separate inclusion of this cost (equation 3g) should also add increased sensitivity to the variance in vendors lead times as the safety stock handling cost will in general be large for larger amounts of safety stock.

D. Dynamic Programming Algorithm

The dynamic programming algorithm, which determines the optimal policy, will now be introduced. Let u_i be the equivalent warehouse space allocated to item i and $Y_i(u_i)$ be the minimum expected cost of allocating u_i to item i. Then:

$$Y_i(u_i) = \min_{q_{iv}} \quad Q(q_{iv}) \tag{5}$$

$$\text{where } q_{iv} \geq M_{iv} \geq 0 \tag{6a}$$

$$q_{iv} \leq D_i \tag{6b}$$

$$q_{iv} \geq r_{iv} \tag{6c}$$

$$\left[\frac{q_{iv}}{ALPHA}\right]^+ \leq u_i \tag{6d}$$

We may observe that the constraint $q_{iv} \geq M_{iv}$ means that the order quantity must be greater than or equal to the minimum order quantity specified for the item by the vendor. The minimum quantity may be zero for some vendors.

The constraint $q_{iv} \leq D_i$ is imposed to restrict order quantities to be no more than one year's demand, as one year is the planning horizon and annual costs are used in the model.

The constraint $q_{iv} \geq r_{iv}$ ensures that the quantity ordered is sufficient to return the quantity on hand back to the reorder point the desired BETA percent of the time.

The constraint $\left[\frac{q_{iv}}{\text{ALPHA}}\right]^+ \leq u_i$ needs further clarification. ALPHA, the space utilization factor accounts for the phasing of deliveries so that the proper amount of space may be allocated in the warehouse. Thus the only values of q_{iv} which will be considered in minimizing $Q(q_{iv})$ are those which the space utilization factor indicates will permit the q_{iv} to be stored on arrival.

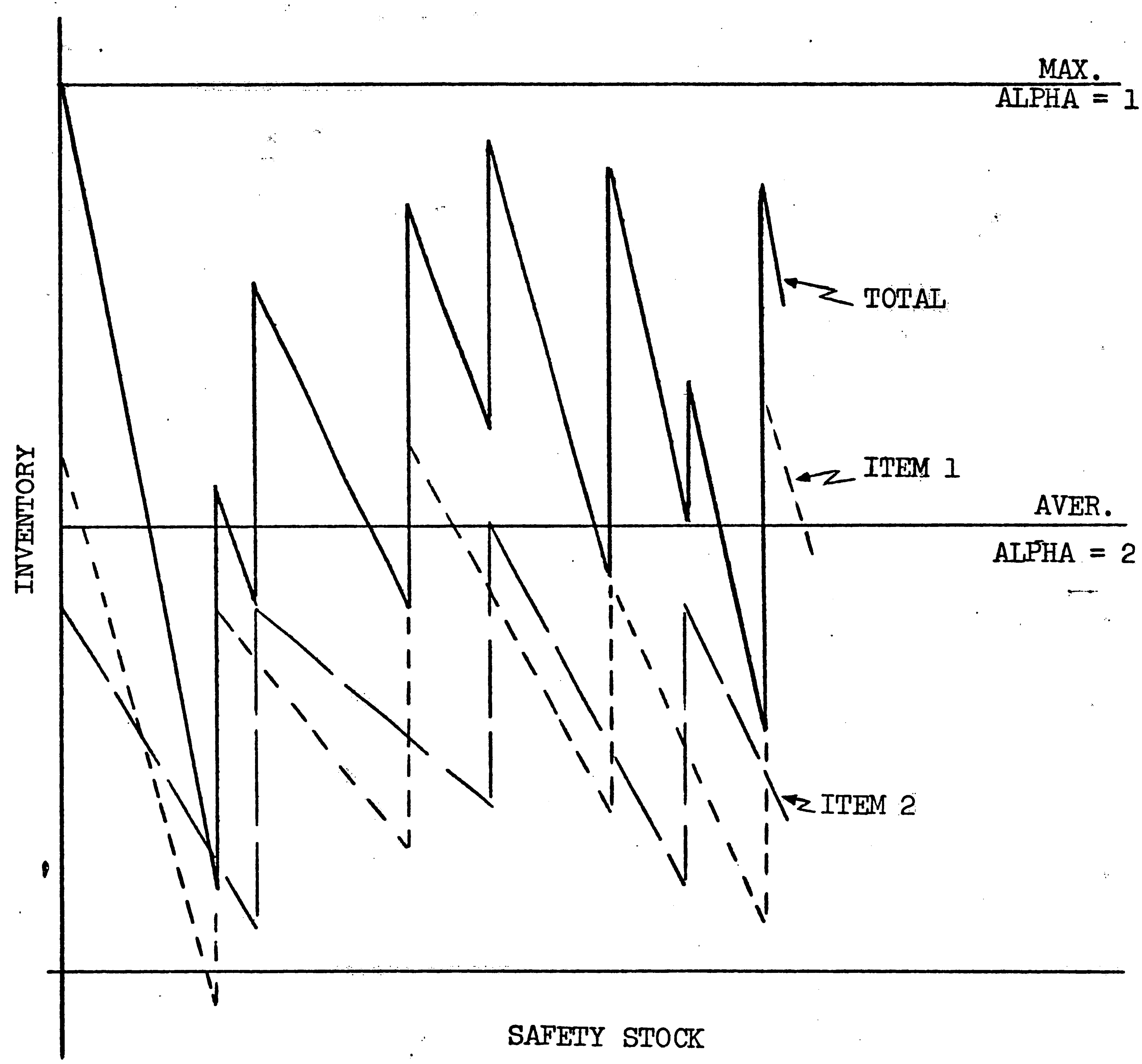
The values of ALPHA are based on the following analysis. If there are N items with safety stocks s_j and order quantities q_j ($j = 1, 2, 3, \ldots, N$), then the maximum number of spaces needed in the warehouse is $\sum_j (s_j + q_j)$. Assuming that deliveries are randomly phased between items, the lower bound on the regular stock is the average of the sum of the order quantities, while the safety stocks are present most of the time and this space may be considered to be allocated at the maximum amount. Thus the lower bound is $\sum_j (s_j + q_j/2)$. In simulation studies (see Siecienski, 8), the spaces required has been found to lie between these bounds and ALPHA ($1.0 \leq \text{ALPHA} \leq 2.0$) may be substituted for the 2 in the preceding expression. Figure 2 illustrates ALPHA for 2 items.

In the case under consideration, backorders are not warehoused, but are supplied directly to the using organization. Thus it is possible for less than one-half of the maximum number of units to be in the warehouse, on the average. An estimate of the upper bound on ALPHA in this case may be derived from the previous case where all deliveries were warehoused. Since BETA is the minimum percent of demands to be filled from inventory, the average inventory is reduced at most to BETA $\cdot \left[\frac{1}{\text{ALPHA}} \sum_j q_j \right]$. This is the same as increasing ALPHA by (ALPHA/BETA) which has a maximum value of (2/BETA). Thus if BETA is .90 then the maximum value of ALPHA may be considered to be 2/.90 = 2.22.

In the adaptive model, the information supplied by the simulation is utilized to find the correct value of ALPHA. An initial estimate of ALPHA is provided and new estimates are obtained, using exponential smoothing once again to reduce the effect of variance in the simulation. The expression for this process is:

$$\begin{aligned} \text{ALPHA}_{\text{new}} &= (\text{ALPHA}_{\text{old}}) \cdot (1-A) \\ &\quad + A \cdot \left(\sum_i q^*_{iv} / \text{AVER INV} \right) \end{aligned} \qquad (7)$$

where $0 < A < 1$, $i = 1, 2, 3 \ldots, I$, and



NOTE: STOCHASTIC DEMAND APPROXIMATED BY STRAIGHT LINES

FIGURE 2 - SPACE UTILIZATION FACTOR FOR TWO ITEMS

AVER INV is the sum of all beginning regular stock inventories for a year of simulation divided by 250, the number of business days in the year.

In preliminary runs, it was found that the safety stock rental cost was consistently somewhat more in the procurement planning submodel than the costs obtained in the simulation. The cause of this bias was found to be the withdrawal of safety stocks, as should have been expected. Since the safety stocks are considered to be stored in a separate space, a safety stock utilization factor, DELTA, was introduced. DELTA is initialized at 1.0 and adaptively updated by:

$$\text{DELTA}_{old} = (\text{DELTA}_{new}) \cdot (1-A) + A \cdot \left(\sum_i \text{NSS}_{iv} / \text{SS INV}\right) \qquad (8)$$

where $0 < A < 1$, $(i = 1, 2, 3, \ldots, I)$, NSS_{iv} is the safety stock for item i in the current policy, and SS INV is the sum of all the beginning safety stock inventories for a year of simulation divided by 250.

As noted previously, dynamic programming is used to find q^*_{iv} the optimal order quantity to be ordered from vendor v for each i resulting in the minimum cost $Y_i(u_i)$. Suppose w_I is the total warehouse space for I items and u_1 is space associated with $Y_1(u_1)$ for the first item.#

#The ranking of items does not affect the solution.

Then $w_{I-1} = w_I - u_1$ is the space available for the remaining I-1 items. Let $f_1(w_1)$ be the minimum cost function associated with item 1. Then $f_2(w_2)$ is:

$$f_2(w_2) = \underset{u_2}{\text{MIN}} \left\{ (Y_2(u_2) + f_1(w_2 - u_2) \right\} \tag{9}$$

and the general functional equation is:

$$f_i(w_i) = \underset{u_i}{\text{MIN}} \left\{ (Y_i(u_I) + f_{i-1}(w_i - u_i) \right\} \tag{10}$$

It is necessary to compute $TC(w_I)$, the total annual cost for handling, warehousing and procurement for each feasible warehouse size w_I before the optimal size warehouse w_I^* can be found. $TC(w_I)$ is the sum of the following annual costs:

Regular stock handling cost =

$$2H\left[\sum_i D_i - \sum_i \frac{D_i}{q_{iv}} \sum_{X=L_{iv}}^{r_{iv}} (x - L_{iv})h(x)\right] \tag{11}$$

where $L_{iv} = r_{iv} - ss_{iv}$

$$\text{Regular stock rental cost} = p(w_I - \sum_i ss_{iv}) \tag{12}$$

$$\text{Procurement cost} = \sum_i Q(q_{iv}) \tag{13}$$

Then the optimal value of $TC(w_I^*)$ is:

$$TC(w_I^*) = \underset{w_I}{\text{MIN}}\ TC(w_I) \tag{14}$$

where w_I ranges over the feasible warehouse sizes for I items.

Finally, the optimal values of q_{iv}, ss_{iv} and v may be found by a backward pass through the values associated with w_I^* for all items. These quantities in addition to the reorder point r_{iv} for vendor v for each i, form the output from the procurement submodel which are used in the simulation submodel.

E. Simulation Submodel

The simulation submodel represents the procurement system which was defined at the beginning of this chapter and interacts with the planning submodel as just described. Since this material has been already covered in detail, it would be redundant to cover it at this point. However, there are several features of the simulation submodel which have not been explained.

Demands are drawn from the Poisson distribution, while lead times are drawn from either the normal or the gamma distributions according to the vendor. These distributions are generated by subroutines commonly used in simulation work. The sources of these subroutines and comments on their application are contained in Appendix A for reference.

The convolution program in the procurement planning submodel requires that the lead time sample distribution be in the form of a discrete probability distribution. This function is performed by sorting the generated lead times (including the initial estimate) and calculating the probability of occurrence for each lead time based on the current sample. This process occurs at the end of each simulation before the planning for the next year's policy is implemented.

Orders are generated in the simulation submodel on the basis of the inventory position in relation to the reorder point, r_{iv}, for each item. The inventory position is defined as the amount on order, plus the inventory on hand minus the amount back ordered. The relationship of these quantities is shown in Figure 3.

As can be seen in the figure, use of the inventory position to trigger an order ensures that orders will continue to be placed even though the previous order has not been received. If the inventory on hand were used for this purpose, the need for ordering could not be sensed during the time that the inventory was below the reorder point. In the case under consideration, backorders are permitted and there is no initial information on the variance of the vendor's lead time. Thus situations can easily arise when it is necessary to reorder before the previous order has arrived. This point will be discussed in more detail in Chapter III, when deviations from the theoretical basis of the procurement planning submodel are discussed.

F. Collection of Statistics

Statistics are collected in both the procurement planning submodel and the simulation submodel. The purpose of these statistics is:

1. Provide sufficient information to ensure that the model is operating properly.
2. Provide the data from simulations to meet the goals previously stated.
3. Provide data on certain aspects of the model noted during development that are interesting and furnish

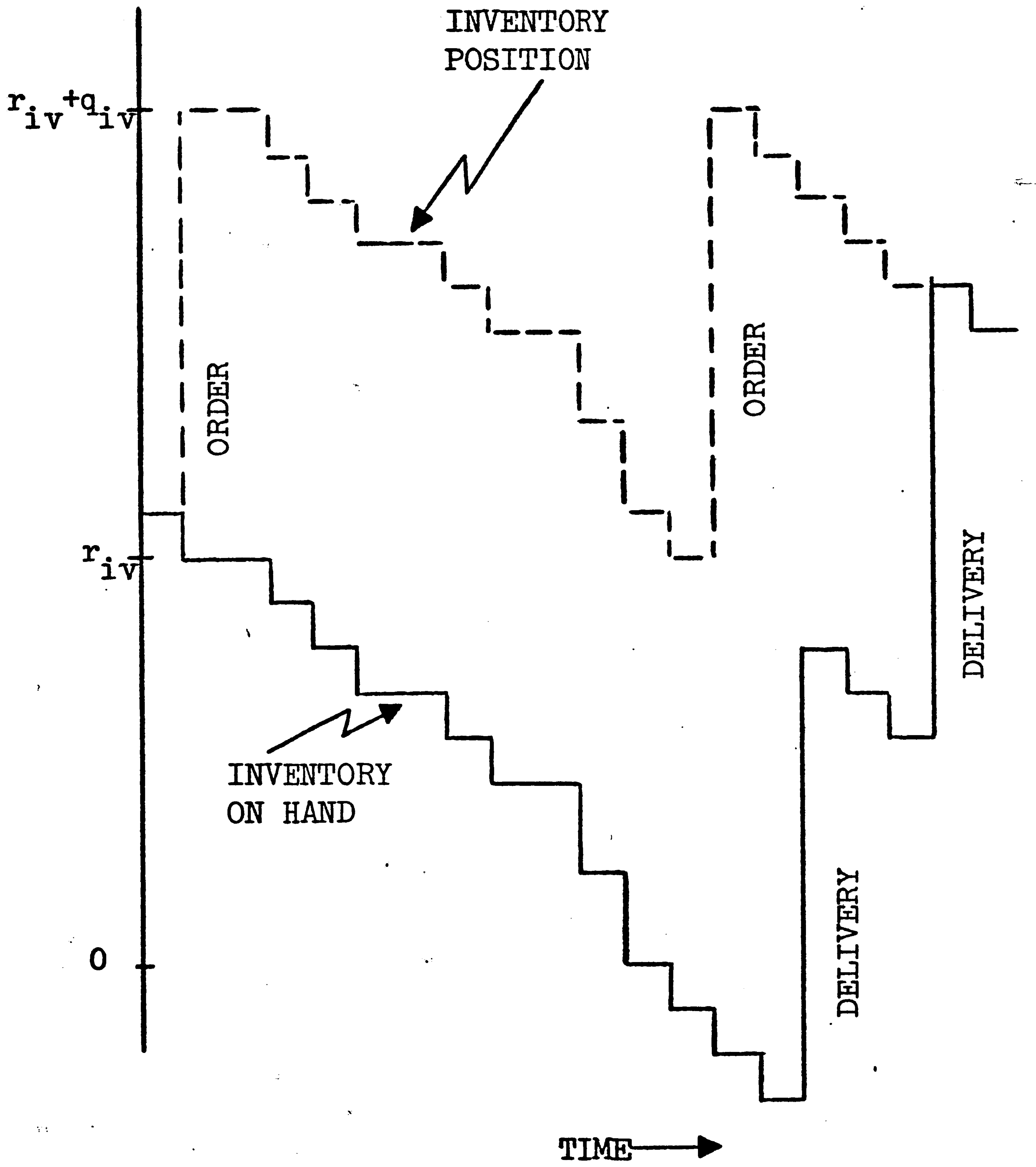


FIGURE 3- RELATION OF THE INVENTORY POSITION TO THE INVENTORY ON HAND

further insight into the model and the environment it represents.

The scheme used in collection was to summarize the statistics into tables with column headings that would readily identify the data. There are eight different tables of this type and an example of each is contained in Appendix B for reference. The Fortran coding of the program provides a listing of every transaction in the simulation. However, these listings are voluminous and are chiefly useful for debugging. In the simulation runs, output of this data is suppressed in favor of the tabular summaries.

G. Program Size and Execution

As noted in Chapter I, the dynamic programming algorithm is limited by core size and execution requirements. Additional core is required for collecting statistics and passing information between the submodels of the adoptive model. Since core size and execution depend upon the number of vendors and items, the program was restricted to two items and four vendors in order to facilitate the investigation.

Execution was performed on a PDP-10 in time sharing mode, requiring 21K of core, and from .25 to 1.0 minutes of CPU time per year of planning.

CHAPTER III

THE MODEL AND ENVIRONMENT

A. Purpose

The purpose of this chapter is to analyze pertinent aspects of the model in relationship to the environment as a basis for the simulation experiments. As a consequence of service level considerations, another mode of operating the model will be developed.

B. Vendor Characterization

It was noted in the description of the simulation submodel that lead times are drawn from the normal and gamma distributions. These distributions are frequently used to represent stochastic lead times since, with appropriate choice of parameters, real world conditions can be often approximated.

Hadley and Whitin [7] (p. 203) observe that the gamma distribution is particularly suitable for this use as the shape can be varied to fit a variety of empirical distributions.

Vendors will be assumed to be characterized by their lead time distributions and minimum order quantities (MOQ). Four vendors will be considered in the simulation with the lead time distribution and the relative minimum order quantity shown in Table 1.

TABLE 1

Vendor	Lead Time Distribution	MOQ
1	Normal	High
2	Gamma	High
3	Normal	Low
4	Gamma	Low

To create a competitive situation between the vendors, the normal distribution will be chosen with a variance smaller than the gamma distribution and the modal values of the two distributions will be set to the same value.

In this scheme, the normal distribution of lead time, with its symmetry and smaller variance, will be considered to represent a vendor with a well controlled operation. Conversely the vendor with a gamma distribution of lead time will be considered to have more variability in his operation resulting in a greater variance of deliveries. The unit and setup costs of the vendor with normally distributed lead times are imputed to be higher, due to the costs of scheduling and control, than the costs of the vendor with the gamma distribution of lead times.

The MOQ value can be analyzed in a similar manner. The higher value of MOQ implies a vendor operating at a higher level of production resulting in lower unit costs, but higher set up costs due to the complexity of factors such as scheduling men and machines. While the lower value of MOQ (assumed to be zero) indicates a vendor with a smaller volume which results in higher unit costs, but a more flexible operation resulting in lower setup costs.

Now by combining the relative costs associated with the lead time distribution and the MOQ for each vendor, the following relationships are obtained.

setup cost:

$$\text{VENDOR 1} > \text{VENDOR 2} > \text{VENDOR 3} > \text{VENDOR 4} \qquad (15)$$

unit cost:

$$\text{VENDOR 2} < \text{VENDOR 1} < \text{VENDOR 4} < \text{VENDOR 3} \quad (16)$$

These relative cost positions will be maintained throughout the simulation. Although in some cases the strict inequality may be changed to a $\leq$ condition to explore sensitivity. It is not claimed that this method of analysis universally true, but that it is reasonable in the context of the previous assumptions.

The modal values of the gamma and the normal distributions are set to the same value to create a competitive situation in which the vendor is assumed to act in his best interest. When asked for an estimate of his average lead time, three different concepts may occur to the vendor. These are the mode, mean and median. For a symmetric distribution such as the normal, these values are identical. However, the gamma is skewed to the right which makes the relative magnitude:

$$\text{mode} < \text{median} < \text{mean} \quad (17)$$

Since the mode is the smallest of the three measures, it would be in the best interest of the vendor to supply this value as the estimate. It is presumed that the vendor as an independent entrepreneur will realize that the shorter lead time is more attractive to a potential customer, and will hope that if a contract is obtained, the customer will not discern that the mean lead time is a larger figure.

It is recognized that in the long run the larger mean and variance of the gamma distributions selected should discriminate against selecting vendors with this lead time distribution. However, this factor should be offset by the lower unit and setup costs which have been imputed. The ability of the model to discriminate among these factors is one objective of this thesis. It is believed that an effective measure of this discrimination is the period taken for stability in vendor selection and the variation in periods and vendors between simulation runs.

The following example is provided to present a clearer picture of the relative means and variances of the normal and gamma distributions that will be used.

The probability density function f(x) of the gamma distribution is given in many probability texts such as Meyer.[9] The function is:

$$f(x) = \frac{b}{(K-1)!}(bx)^{K-1}e^{-bx} \tag{18}$$

$$\text{with mean } E(x) = K/b \tag{19}$$

$$\text{and variance } V(x) = K/b^2 \tag{20}$$

Since f(x) is unimodal and continuous, the mode may be found by:

$$f' = (K-1)(bx)^{K-2}-(bx)^{K-1} = 0 \tag{21}$$

$$\therefore b = (K-1)/x \tag{22}$$

Let k=4 and the competing normal distribution be n (15,9). As the modes are chosen to be equal, the mode of the gamma will be 15.

$$\therefore b = (4-1)/15 = .2 \tag{23}$$

Thus the parameters of the gamma are determined. The mean and variance are:

$$E(x) = K/b = 4/.2 = 20 \tag{24}$$

$$V(x) = K/b^2 = 4/(.2)^2 = 100 \tag{25}$$

It will be noted that the mean and variance have been controlled by selecting the value of K. This parameter is not constrained to be an integer, but we will use integer values for convenience of computation.

C. Demand Characterization

The annual demand for each item is assumed to be known with a daily demand that is Poisson distributed. Thus the mean daily demand is the annual demand divided by 250, the number of business days. This completely specificies the Poisson distribution, a distribution with only one parameter which is equal to both the mean and the variance.

It is felt that a Poisson distributed demand is reasonable for the system we have modeled, since the distribution is discrete and the probability of demands for more than one unit would be relatively small. Discreteness is important since we are considering demands for pallet loads, a relatively large amount, in a system that performs transactions once each day. Annual demands will be considered in the range up to 250 pallets, which limits demands to a mean of one each day. Thus demands for more than one pallet should occur relatively infrequently and can be considered to be peak demands caused by factors such as phasing of demands for multi-user items or peaks in production. It is felt that some peaking of this sort will occur in most industrial situations if transactions are recorded on a daily basis. Poisson distributed demands with larger means are easily envisioned, but will not be considered in this thesis.

D. Theoretical Considerations

It should be pointed out that the use of the Poisson distribution to represent demands is an infringement on the theoretical basis of the model, since the reorder point may be overshot by demands of two more pallets. In these cases the usage during lead time is increased by the amount of the overshoot. For example, if the inventory level is one pallet above the reorder point, and a demand of two pallets occurs, then the usage during lead time will be increased by one pallet which was not considered in the convolution of lead time and demand distributions.

However, as stated in the previous section, the mean daily demand will be limited to one unit. The probability of two or more units being demanded with a Poisson distribution with mean of 1 is .2642 and the probability decreases for smaller means. This limits the effect of overshooting the reorder point, but retains the real world effect of demand peaks.

When discussing the use of the inventory position for triggering orders, it was pointed out that it is possible to have more than one order outstanding. It is common to ignore this possibility in developing a model since it is difficult to handle mathematically. A further complexity is the possibility that the first order placed may not be the first order delivered. This phenomenon is commonly referred to as order crossing.

There are several conservative features in the method of setting the reorder point that will tend to offset the preceding deviations.

Recall from Chapter II that the reorder point is defined by the relation:

$$\Pr(z_{iv} > r_{iv}) \leq 1 - \text{BETA} \tag{26}$$

Since the usage is in integral pallet loads, the probabilities associated with each succeeding usage during lead time (z_{iv}) change considerably. Thus the case $\left\{\Pr(z_{iv} > r_{iv}) = 1 - \text{BETA}\right\}$ is realized infrequently. This effectively raises the service level (BETA) above that set by management. Suppose BETA is .950. The probability of using 10 units during a lead time may be .947 and the probability of using 11 units may be .955. Thus 11 units would be chosen as the reorder point (r_{iv}) raising BETA to .955.

A sample of 20 different demands and 6 different lead times for each demand was taken to illustrate this point. The desired BETA was again .950. In the sample (120 points) the mean probability at the reorder point was .9648 with variance .0088.

Another conservative feature of the model is the safety stock (ss_{iv}) calculation which uses rounding up. This expression is:

$$ss_{iv} = \left[r_{iv} - z_{iv}\right]^{+} \tag{27}$$

As noted in Chapter II, the rounding up increases the amount of the safety stock by a fraction of a pallet and places a lower bound of one pallet on the amount of safety stock.

Since the net effect of these conservative methods and the stated deviations would be difficult to handle analytically, data on the deviations will be collected during the simulation.

E. Service Level Definition

In the development of the model and the preceding section, the service level has been considered strictly as a function of the probability of a stockout during a lead time. This definition is well suited to the dynamic programming algorithm, since the reorder point (r_{iv}) can be set independently of the order quantity (q_{iv}). Further interaction between r_{iv} and q_{iv} is not necessary in the algorithm except quantities are not considered which violate the constraint $q_{iv} \geq r_{iv}$.

Hence, the various feasible order quantities can be considered without recomputing the reorder point and the associated safety stock. This provides considerable savings in computation and simplicity in the model.

However, the service level provided is not entirely realistic from an operational viewpoint. The service level is a management variable which is dependent upon a degree of judgment. While models such as used in this thesis can be constructed so that costs and other factors can be compared at various levels of service, it is claimed that the service level chosen by management will still be affected by factors which are intangible or in some other manner beyond the scope of the model. From this viewpoint, it seems more reasonable to define the service level during the entire period of operations, as the manager should find this definition closer to his perspective than service during a lead time.

Therefore, the service level for each item will be computed on an annual basis in the simulation by:

$$\frac{\text{number of demands for the items in the year filled from inventory}}{\text{total number of demands for the item in the year}} \qquad (28)$$

This expression will define the service level based on demand ($BETA_{dem}$) to differentiate from the service level based on days ($BETA_{days}$) which will be defined by:

$$\text{BETA days} = \frac{\text{number of days in the year demands are met for an item}}{250} \qquad (29)$$

where 250 is the number of business days in the year.

The latter definition of service level was not considered in the construction of the model. However, the percentage of days that demand was met is sometimes requested by managers to gain further insight into service being provided and the data is collected on this basis.

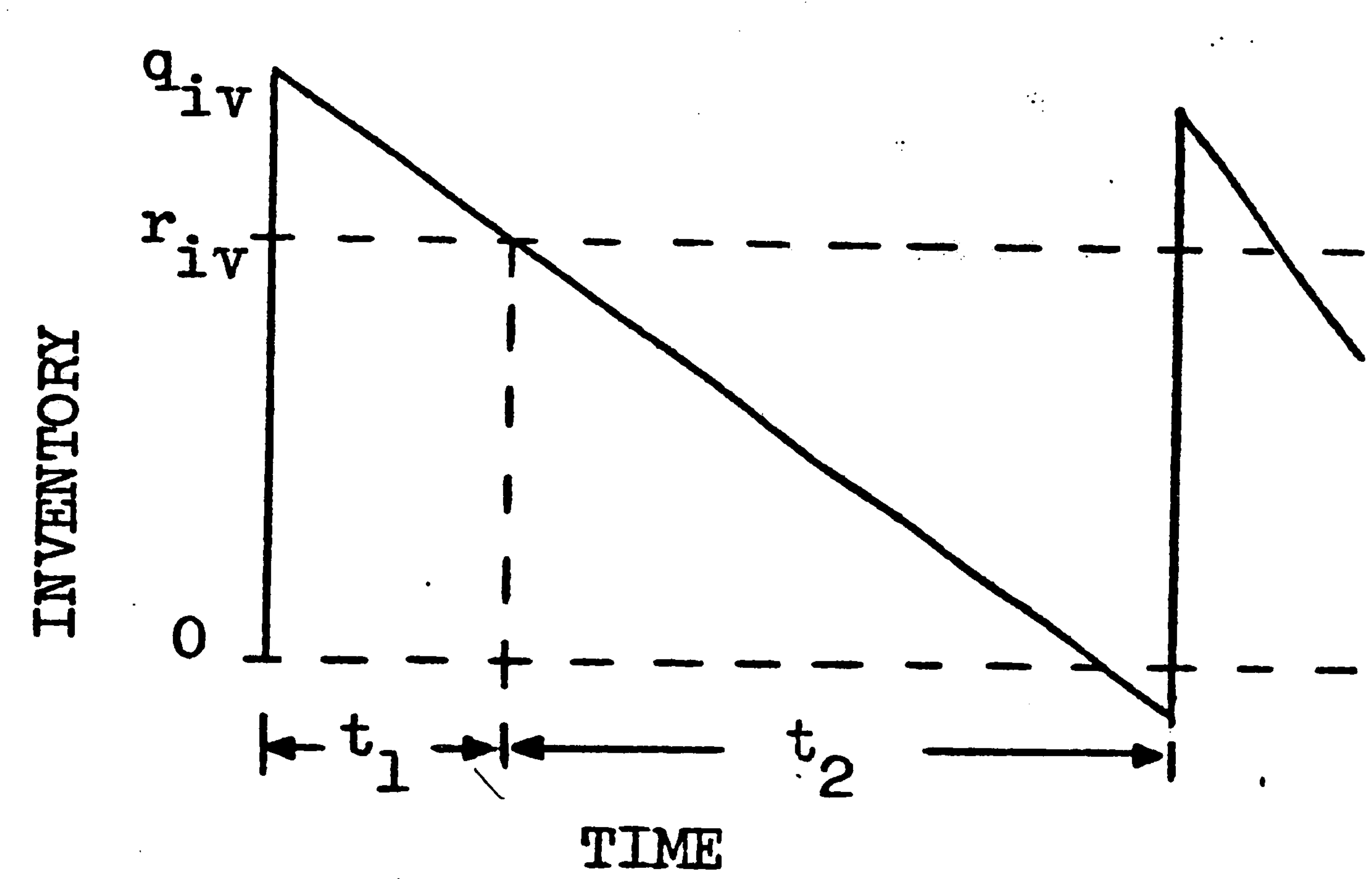


FIGURE 4 - SIMPLIFIED ORDER CYCLE

Figure 4 shows the relationships of the order quantity (q_{iv}), reorder point (r_{iv}) and the time segments (t_1, t_2) of an order cycle.

This figure is simplified for purposes of explanation and assumes that only one order can be open at a time, an assumption which will be retained in the following analysis. It will be noted that $\bar{t}_1$ represents the time from delivery of one order until another order is placed and t_2 represents the lead time.

Demands should always be filled from inventory in time segment t_1 and BETA percent of the demands in time segment t_2. Therefore, the service level during the entire cycle ($BETA_{cy}$) is:

$$BETA_{cy} = \frac{t_1 + BETA \cdot t_2}{t_1 + t_2} = BETA + \left[\frac{1 - BETA}{t_1 + t_2}\right] \cdot t_1 \tag{30}$$

$$\therefore\ BETA_{cy} \geq BETA, \text{ as } BETA \leq 1 \tag{31}$$

Now consider that there are K order cycles in a year and any cycle k has an associated $(BETA_{cy})_k$. Thus we can find an expression for $BETA_{dem}$:

$$BETA_{dem} = \frac{1}{K} \sum_k (BETA_{cy})_k \tag{32}$$

And since $(BETA_{cy})_k \geq BETA$ for all k we may write $BETA_{dem} \geq BETA$.

F. The Adaptive BETA Mode

These relations for different definitions of the service level suggest another mode for operating the adaptive model. Since $BETA_{dem} \geq BETA$, it may be desirable to operate the model so that BETA is successively reduced until $BETA_{dem}$ approaches the desired service level. This should be a conservative approach since $BETA_{dem}$ will be potentially higher in the early years when information on the vendor's lead time is inadequate.

This method of operation will be termed the beta adaptive mode and will operate under the following rules. Let BETA be the desired service level as previously defined. Now define the effective service level $(BETA_{eff})_i$ where i represents any item i (i = 1,2,3 ...,I). In the first year, let $(BETA_{eff})_i$ = BETA for all i. At the end of each simulated year form the following difference:

$$DIFF_i = (BETA_{dem})_i - (BETA_{eff})_i \qquad (33)$$

$$\text{If:} \quad (BETA_{dem})_i < BETA \qquad (34)$$

$$\text{And:} \quad ss_{iv} \geq 1 \qquad (35)$$

$$= 0 \text{ otherwise}$$

Then form a new value of $(BETA_{eff})_i$ by:

$$BETAM1 = 1 - OLD\ (BETA_{eff})_i \qquad (36)$$

$$NEW\ BETAM1 = OLD\ BETAM1 + E \cdot DIFF_i \qquad (37)$$

$$NEW\ (BETA_{eff})_i = 1 - NEW\ BETAM1 \qquad (38)$$

$$\text{where } 0 < E < 1$$

Then use NEW $(BETA_{eff})_i$ as the value of service level for item i in the procurement submodel for the next year's computations.

The first constraint (34) on $DIFF_i$ forces it to zero if the observed service level based on demand is less than the desired service level. This constraint also forces $DIFF_i$ to zero if $(BETA_{dem})_i < (BETA_{eff})_i$, since $BETA \geq (BETA_{eff})_i$. The effective service level will be reduced incrementally until $DIFF_i$ is consistently forced to zero.

A lower bound on the effective service level results from the constraint $ss_{iv} \geq 1$. Recall from Chapter II that:

$$ss_{iv} = [r_{iv} - \bar{z}_{iv}]^+ \tag{39}$$

Recall also that the reorder quantity (q_{iv}) is constrained by:

$$q_{iv} \geq r_{iv} \tag{40}$$

$$\text{if } ss_{iv} = 1,\ q_{iv} \geq [\bar{z}_{iv}]^+ \tag{41}$$

The constraint $q_{iv} \geq [\bar{z}_{iv}]^+$ is required to prevent the accumulation of backorders. If q_{iv} were less than $[z_{iv}]^+$ by say one unit, then on the average one more unit will be used during a lead time than will be delivered at the end of the lead time.

It is planned to perform simulation runs in the normal mode where BETA is fixed (fixed beta mode) and in the adaptive beta mode in order to compare:

1. Total cost
2. Service levels
3. Vendor selection

CHAPTER IV

SIMULATION RESULTS

A. Initial Conditions

The inventory was initialized at the reorder point for each item in the first year of simulation. Thus an order is placed the first time an item is demanded. This approach was taken to maintain a consistent starting condition and to avoid biasing the results of the first year's simulation. It is apparent that starting with inventory greater than the reorder point will provide a higher initial service level, while starting the inventory below the reorder point will lower the service level.

There are three parameters in the model which are initialized at estimated values and are changed to new estimates based on information provided by the simulation. These parameters were initialized at the values listed below.

ALPHA = 2.0 (Space utilization factor for regular stock)

DELTA = 1.0 (Space utilization factor for safety stock)

T_i = 1.0; i = 1,2 (Probability of an overstock when item i is received)

The model contains two parameters which are set at the discretion of the user. Unless otherwise noted, the following values will be used for these parameters.

A = 0.1 (Coefficient used in exponential smoothing of ALPHA, DELTA and T_i)

E = 0.5 (Coefficient used in adaptive beta mode)

The mean demand for item 1 was set at .6 pallets per day and the mean demand for item 2 was set at .25 pallets per day. The relative magnitudes of the demands were chosen so that:

1. The demands for items 1 and 2 would be relatively different.
2. There would be a definite probability of two or more items being demanded in a day to retain the desired effects of demand peaks.
3. The greatest demand would be well within the limit of 1.0 pallet per day selected to restrict the effect of 2 or more units being demanded.

The exact values of demands were chosen arbitrarily so that the relative magnitude requirements were met.

Appendix C contains a summary of costs, number of units per pallet and minimum order quantities. Various unit and vendor setup costs are used to explore sensitivity. These costs are tabulated in Appendix C according to cost profile numbers. The lead time estimate chosen was 15 days. The lead time distributions are summarized in Table 2 and are consistent with the parameters in the example of Chapter III.

TABLE 2

Vendor	Distribution of Lead Time
1	normal; var = 9, mean = 15
2	gamma; var = 100, mean = 20
3	normal; var = 9, mean = 15
4	gamma; var = 100, mean = 20

B. Selection of Seeds

Each simulation run was started with a different seed and new seeds were generated during the run by a return from the random number generator. Starting seeds were selected at approximately 50 year intervals from a test simulation, to avoid repetition of sequences where a run was performed for 20 years. The same set of starting seeds were used throughout these experiments.

In the first year service level experiment, seeds were saved at the end of each sample to start the next sample.

C. Number of Simulation Runs

The number of simulation runs was selected by examining the variances of the mean total planned and total simulated costs. The mean costs were computed for the twenty year period in a run and it was found that after ten runs the variances were no longer increasing. Therefore, it was decided to perform ten runs under each experimental condition, except for the first year of service experiment which is described below.

D. First Year Service Results

Since the initial information on lead time has been restricted to an estimate of the average, the service level during the first year is of special interest. Samples of 500 simulations of the first year were run on each item for desired service levels of .90 and .95. Histograms of the observed service levels based on demand are shown in Figures 5, 6, 7 and 8. Three replications of the experiment were run with similar results.

DESIRED SERVICE LEVEL = .90
MEAN OF OBSERVED SERVICE LEVELS = .941
VARIANCE OF OBSERVED SERVICE LEVELS = .003

SERVICE LEVEL	NUMBER OF OBSERVATIONS	
.715	1	X
.730	0	
.745	1	X
.760	3	XX
.775	3	XX
.790	3	XX
.805	6	XXX
.820	9	XXXXX
.835	8	XXXX
.850	10	XXXXX
.865	22	XXXXXXXXXXX
.880	19	XXXXXXXXX
.895	33	XXXXXXXXXXXXXXXX
.910	34	XXXXXXXXXXXXXXXXX
.925	45	XXXXXXXXXXXXXXXXXXXXXXX
.940	48	XXXXXXXXXXXXXXXXXXXXXXXX
.955	64	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.970	57	XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
.985	48	XXXXXXXXXXXXXXXXXXXXXXXX
1.000	86	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

FIGURE 5 - FIRST YEAR SERVICE LEVELS FOR ITEM 1

DESIRED SERVICE LEVEL = .90
MEAN OF OBSERVED SERVICE LEVELS = .965
VARIANCE OF OBSERVED SERVICE LEVELS = .002

```
 SERVICE     NUMBER OF
 LEVEL       OBSERVATIONS

  .680        1  X
  .700        0
  .720        0
  .740        0
  .760        0
  .780        1  X
  .800        3  X
  .820        1  X
  .840       10  XX
  .860       10  XX
  .880       22  XXXX
  .900       24  XXXXX
  .920       25  XXXXX
  .940       44  XXXXXXXXX
  .960       60  XXXXXXXXXXXX
  .980       77  XXXXXXXXXXXXXXX
 1.000      222  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

FIGURE 6 - FIRST YEAR SERVICE LEVELS FOR ITEM 2

DESIRED SERVICE LEVEL = .95
MEAN OF OBSERVED SERVICE LEVELS = .948
VARIANCE OF OBSERVED SERVICE LEVELS = .003

SERVICE LEVEL	NUMBER OF OBSERVATIONS	
.680	0	
.700	1	X
.720	0	
.740	0	
.760	2	X
.780	1	X
.800	1	X
.820	9	XXX
.840	13	XXXX
.860	15	XXXXX
.880	29	XXXXXXXXXXX
.900	33	XXXXXXXXXXXX
.920	52	XXXXXXXXXXXXXXXXXX
.940	57	XXXXXXXXXXXXXXXXXXXX
.960	79	XXXXXXXXXXXXXXXXXXXXXXXXXXXX
.980	70	XXXXXXXXXXXXXXXXXXXXXXXXX
1.000	137	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

FIGURE 7 - FIRST YEAR SERVICE LEVELS FOR ITEM 1

DESIRED SERVICE LEVEL = .95
MEAN OF OBSERVED SERVICE LEVELS = .962
VARIANCE OF OBSERVED SERVICE LEVELS = .002

SERVICE LEVEL	NUMBER OF OBSERVATIONS	
.680	1	X
.700	0	
.720	0	
.740	0	
.760	0	
.780	1	X
.800	5	X
.820	2	X
.840	7	XX
.860	13	XXX
.880	12	XXX
.900	33	XXXXXXXX
.920	30	XXXXXXX
.940	50	XXXXXXXXXXXX
.960	79	XXXXXXXXXXXXXXXXXX
.980	74	XXXXXXXXXXXXXXXXX
1.000	193	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

FIGURE 8 - FIRST YEAR SERVICE LEVELS FOR ITEM 2

In this experiment, 50 percent of the observed service levels were greater than the desired service level (BETA) and 95 percent of the observed service levels were greater than .9 BETA. A greater probability of achieving the desired service level in the first year could be obtained by inflating the value of BETA supplied to the model. This approach would provide a .90 level of service 87.7 and 93.8 percent of the time for items 1 and 2 respectively in the given samples, if the value of BETA were inflated from .90 to .95.

E. Stability Results

It will be recalled from Chapter III that the criterion for stability was chosen as a test of runs on vendor selection at a .05 level of significance. Selection of the same vendor for eight consecutive years (see Duncan[6]) is evidence of non-random influence which is interpreted as a stable condition in our case.

Stability results are displayed in tabular form with entries of the number of years required to achieve stability in a simulation run and the associated vendor. In cases where another vendor was selected after eight consecutive selections of the indicated vendor, an asterisk is inserted by the entry. If stability was not achieved in the twenty year period of a simulation, dashes are entered in the table.

Table 3 shows stability results for item 1 in the fixed beta mode for three different setup costs (cost profiles 1, 2 and 3) with .90 and .95 desired service levels. No significant changes occur between different conditions in this table. The same conditions are repeated for item 2 in Table 4. There are notable differences among the cost profile columns in this table. The relative changes in setup costs were greater for item 2 than item 1. Thus it is concluded that vendor selection is sensitive to relatively large changes in setup costs.

Tables 5 and 6 show stability results for the same conditions as Tables 3 and 4 except that the adaptive beta mode was employed. The columns for the same service level have no significant differences even for item 2, indicating decreased sensitivity to setup costs. However, it will be noted that there is a marked increase in selection of vendor 1 at the .95 service level as opposed to the .90 service level. This is interpreted as a preference for a smaller mean and variance in lead time at a higher service level. This preference is displayed to a lesser degree in Tables 4 and 6 where vendors 1 and 3 are more prominent at the .95 service level than the .90 level.

A greater differentiation will be observed between Tables 3 and 4 and Tables 5 and 6 respectively. Vendors 1 and 3 prevail in the entries of Tables 3 and 4, while vendors 2 and 4 prevail in the entries of Tables 5 and 6. This is interpreted as the preference for the smaller mean and variance of the normal lead time distributions in the fixed beta mode and a preference for the larger mean and variance of the gamma lead time distributions in the adaptive beta mode. These preferences are explained by the effective service levels in the respective modes. As shown in Chapter III, the effective service level is higher in the fixed beta mode than in the adaptive beta mode. The model chooses the smaller lead time mean and variance to maintain the higher service level, although the vendor cost is higher, in the fixed beta mode. The larger mean and variance of the gamma distributed lead times are not a constraint to the service levels in the adaptive beta mode and the lower costs make these vendors attractive. These factors will be further verified by the service level and cost results (sections F and G).

Tables 7, 8, 9 and 10 show stability data for three values of A, the coefficient used in exponential smoothing of the space factors and probabilities of overstocking. It will be observed that there is no significant variation between the columns for the same service level within each table, indicating a robustness in the model for the value of A. A comparison of Tables 7 and 8 (fixed beta mode) to Tables 9 and 10 (adaptive beta mode) shows the same vendor preferences noted previously (Tables 3, 4, 5 and 6) for each mode. Vendors 1 and 3 prevail in the fixed beta mode while vendors 2 and 4 prevail in the adaptive beta mode.

A comparison of vendor selection for small changes in unit costs is made in Table 11 for the fixed beta mode and in Table 12 for the adaptive beta mode. It is claimed that there are differences between the vendor's selected for each comparison in Table 11. For example, item 1 at .90 service level has vendor 2 selected twice and vendor 1 marked with an asterisk twice for cost profile 4, while vendor 1 is uniformly selected without qualification for cost profile 2. Examination of item 2 in Table 12 shows more distinctive differences. Hence, it is concluded that vendor selection by the model is relatively sensitive to unit cost changes.

TABLE 3

STABILITY DATA FOR DIFFERENT SETUP COSTS
ITEM 1 - FIXED BETA MODE

.90 SERVICE LEVEL		
COST PROFILE 1	COST PROFILE 2	COST PROFILE 3
YR-VEND	YR-VEND	YR-VEND
10-1	10-1	14-1
9-1	9-1	9-1
9-1	9-1	9-1
13-1	9-1	10-1
9-1	9-1	9-2*
17-1	14-1	9-1
9-1	9-1	9-1
9-1	9-1	9-1
9-1	9-1	9-1
9-1	9-1	9-1

.95 SERVICE LEVEL		
COST PROFILE 1	COST PROFILE 2	COST PROFILE 3
YR-VEND	YR-VEND	YR-VEND
9-1	9-1	14-1
9-1	9-1	9-1
9-1	9-1	9-1
9-1	9-1	10-1
9-1	9-1	9-1
10-1	10-1	9-2*
9-1	9-1	9-1
9-1	9-1	9-1
10-1	12-1	9-1
9-1	9-1	9-1

TABLE 4

STABILITY DATA FOR DIFFERENT SETUP COSTS
ITEM 2 - FIXED BETA MODE

.90 SERVICE LEVEL		
COST PROFILE 1	COST PROFILE 2	COST PROFILE 3
YR-VEND	YR-VEND	YR-VEND
15-4*	---	17-4
9-3	10-3	10-3*
---	---	---
9-1*	---	16-4
16-1*	15-3	17-4
9-3*	12-1*	13-1
---	---	16-4
9-3*	12-3	12-4
9-3	16-4	15-1
16-3	15-1*	11-3

.95 SERVICE LEVEL		
COST PROFILE 1	COST PROFILE 2	COST PROFILE 3
YR-VEND	YR-VEND	YR-VEND
---	12-1*	14-4
14-1	14-1*	14-1
14-1	11-3	11-3
9-3	16-1	13-4
12-1	---	16-4*
---	15-3	15-3
15-3	10-3	17-4
9-3	11-3	15-3
17-1	---	10-3
---	12-3	17-3

TABLE 5

STABILITY DATA FOR DIFFERENT SETUP COSTS
ITEM 1 - ADAPTIVE BETA MODE

.90 SERVICE LEVEL			.95 SERVICE LEVEL		
COST PROFILE 1	COST PROFILE 2	COST PROFILE 3	COST PROFILE 1	COST PROFILE 2	COST PROFILE 3
YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND
13-2	11-2	8-2	16-2	15-2	15-2
9-1*	9-1*	16-2	9-1	9-1*	9-1*
16-2	15-2	15-2	9-1*	9-1*	9-1*
10-2	10-2	8-2	12-2	12-2	12-2
14-2	14-4	14-2	14-2	13-2	13-2
8-2	8-2	8-2	8-2	8-2	8-2
15-2	15-2	14-2	9-1	9-1	9-1*
15-2	16-2	16-2	9-1*	9-1*	9-1*
14-2	14-2	11-2	17-2	15-2	15-2
13-2	12-2	12-2	9-1*	9-1*	9-1*

TABLE 6

STABILITY DATA FOR DIFFERENT SETUP COSTS
ITEM 2 - ADAPTIVE BETA MODE

.90 SERVICE LEVEL			.95 SERVICE LEVEL		
COST PROFILE 1	COST PROFILE 2	COST PROFILE 3	COST PROFILE 1	COST PROFILE 2	COST PROFILE 3
YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND
15-4*	---	17-4	---	12-1*	14-4
9-3	10-3	10-3*	14-1	14-1*	14-1
---	---	---	14-1	11-3	11-3
9-1*	---	16-4	9-3	16-1	13-4
16-1*	15-3	17-4	12-1	---	16-4*
9-3*	12-1*	13-1	---	15-3	15-3
---	---	16-4	15-3	10-3	17-4
9-3*	12-3	12-4	9-3	11-3	15-3
9-3	16-4	15-1	17-1	---	10-3
16-3	15-1*	11-3	---	12-3	17-3

TABLE 7

STABILITY DATA FOR DIFFERENT VALUES OF A
ITEM 1 - FIXED BETA MODE

.90 SERVICE LEVEL			.95 SERVICE LEVEL		
A = 0.1	A = 0.3	A = 0.5	A = 0.1	A = 0.3	A = 0.5
YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND
10-1	10-1	10-1	9-1	9-1	9-1
9-1	9-1	9-1	9-1	9-1	9-1
9-1	9-1	9-1	9-1	9-1	9-1
13-1	13-1	9-1	9-1	9-1	9-1
9-1	9-1	9-1	9-1	9-1	9-1
17-1	11-1	11-1	10-1	10-1	10-1
9-1	9-1	9-1	9-1	9-1	9-1
9-1	9-1	9-1	9-1	9-1	9-1
9-1	9-1	9-1	10-1	10-1	10-1
9-1	9-1	9-1	9-1	9-1	9-1

TABLE 8

STABILITY DATA FOR DIFFERENT VALUES OF A
ITEM 2 - FIXED BETA MODE

.90 SERVICE LEVEL			.95 SERVICE LEVEL		
A = 0.1	A = 0.3	A = 0.5	A = 0.1	A = 0.3	A = 0.5
YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND
15-4*	---	15-3	---	19-3	10-3
9-3	14-3	11-3	14-1	17-3	14-1
---	14-3	10-3	14-1	18-3	10-3
9-1*	9-3	10-3*	9-3	9-3	15-1
16-1*	---	---	12-1	13-1	---
9-3*	9-3	12-3	---	15-3	10-3
---	18-3	10-3	15-3	11-1*	17-3
9-3*	9-3	9-3	9-3	9-3	9-3
9-3	---	15-3	17-1	14-3	---
16-3	9-3	13-3	---	18-1	10-3

TABLE 9

STABILITY DATA FOR DIFFERENT VALUES OF A
ITEM 1 - ADAPTIVE BETA MODE

.90 SERVICE LEVEL			.95 SERVICE LEVEL		
A = 0.1	A = 0.3	A = 0.5	A = 0.1	A = 0.3	A = 0.5
YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND
13-2	14-2	13-2	16-2	16-2	9-1*
9-1	9-1	9-1*	9-1	9-1*	9-1*
16-2	16-2	16-2	9-1*	9-1*	9-1*
10-2	10-2	13-2	12-2	11-2	14-2
14-2	14-2	9-1	14-2	14-2	13-2
8-2	8-2	8-2	8-2	12-2	12-2
15-2	15-2	15-2	9-1	9-1*	9-1*
15-2	15-2	15-2	9-1*	9-1*	9-1*
14-2	15-2	14-2	17-2	18-2	10-1
13-2	12-2	12-2	9-1*	9-1*	9-1

TABLE 10

STABILITY DATA FOR DIFFERENT VALUES OF A
ITEM 2 - ADAPTIVE BETA MODE

.90 SERVICE LEVEL			.95 SERVICE LEVEL		
A = 0.1	A = 0.3	A = 0.5	A = 0.1	A = 0.3	A = 0.5
YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND
12-4	11-4	8-4	14-3	12-4	12-4
13-4	13-4	13-4	13-4	15-4	13-4
11-4	12-4	14-4	15-4	13-3	15-4
14-4	13-4	13-4	17-4	16-4	16-4
9-3	10-3*	13-4	18-3	11-4	12-4
11-4	11-4	11-4	14-4	14-4	10-3
13-4	11-4	9-3*	9-3	9-3	9-3
12-4	10-3	16-4	9-3	9-3	17-4
8-4	15-4	16-4	13-4	15-3	12-3
11-4*	14-4	13-4	15-3	14-4*	16-4

TABLE 11

STABILITY DATA FOR DIFFERENT UNIT COSTS
FIXED BETA MODE

ITEM 1				ITEM 2			
.90 SERV LEVEL		.95 SERV LEVEL		.90 SERV LEVEL		.95 SERV LEVEL	
COST PROFILE 2	COST PROFILE 4	COST PROFILE 2	COST PROFILE 4	COST PROFILE 2	COST PROFILE 4	COST PROFILE 2	COST PROFILE 4
YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND
10-1	11-1	9-1	14-1	15-4*	10-2	---	14-1
9-1	13-1	9-1	11-1	9-3	19-4	14-1	13-1*
9-1	11-1	9-1	10-1	---	9-4	14-1	12-1*
13-1	10-1	9-1	15-1	9-1*	13-1	9-3	11-3
9-1	8-2	9-1	19-1	16-1*	12-4*	12-1	---
17-1	13-1*	10-1	11-1	9-3	11-1	---	11-1
9-1	9-1*	9-1	11-1	---	15-3	15-3	10-1
9-1	15-1	9-1	14-1	9-3*	---	9-3	13-3
9-1	8-2*	10-1	12-1	9-3	---	17-1	16-3
9-1	9-1	9-1	12-1	16-3	17-1	---	18-2

TABLE 12

STABILITY DATA FOR DIFFERENT UNIT COSTS
ADAPTIVE BETA MODE

ITEM 1				ITEM 2			
.90 SERV LEVEL		.95 SERV LEVEL		.90 SERV LEVEL		.95 SERV LEVEL	
COST PROFILE 2	COST PROFILE 4	COST PROFILE 2	COST PROFILE 4	COST PROFILE 2	COST PROFILE 4	COST PROFILE 2	COST PROFILE 4
YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND
13-2	8-2	16-2	11-2	12-4	8-2	14-3	---
9-1	14-2	9-1	12-1*	13-4	---	13-4*	11-4
16-2	14-2	9-1*	14-2	11-4	10-2*	15-4	12-2*
10-2	8-2	12-2	13-2	14-4	---	17-4	10-1
14-2	8-2	14-2	8-2	9-3	10-2	18-3	16-2*
8-2	8-2	8-2	11-1*	11-4	---	14-4	---
15-2	13-2	9-1	11-1*	13-4	---	9-3	10-2
15-2	16-2	9-1*	14-1*	12-4	10-2	9-3	14-2*
14-2	11-2	17-2	13-2	8-4	---	13-4	19-2
13-2	14-2	9-1*	18-2	11-4*	---	15-3	19-2

TABLE 13

STABILITY DATA FOR DIFFERENT INITIAL VALUES OF ALPHA
SERVICE LEVEL = .90
FIXED BETA MODE

ITEM 1			ITEM 2		
ALPHA=1.5	ALPHA=1.7	ALPHA=2.0	ALPHA=1.5	ALPHA=1.7	ALPHA=2.0
YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND
9-1	9-1*	10-1	11-3	13-3	15-3
10-1	9-1	9-1	14-3	14-3	9-3
9-1	9-1	9-1	15-3	14-3	---
10-1	9-1*	13-1	9-3	9-3	9-3*
9-1	12-1	9-1	16-1	10-3	16-1*
9-1	9-1	17-1	9-3	10-3	9-3*
9-1	10-1	9-1	14-3	13-3	---
10-1	9-1	9-1	18-3	9-3	9-3*
10-1	9-1	9-1	11-3*	15-3	9-3
9-1	12-1	9-1	9-3	12-3	16-3

TABLE 14

STABILITY DATA FOR DIFFERENT INITIAL VALUES OF ALPHA
SERVICE LEVEL = .90
ADAPTIVE BETA MODE

ITEM 1			ITEM 2		
ALPHA=1.5	ALPHA=1.7	ALPHA=2.0	ALPHA=1.5	ALPHA=1.7	ALPHA=2.0
YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND	YR-VEND
11-2	13-2	13-2	8-4	12-4	12-4
9-2	16-2	9-1*	8-4*	12-4	13-4
14-2	11-2	16-2	8-4*	11-4	11-4
8-2	11-2	10-2	18-3	10-4	14-4
12-2	8-2	14-2	11-4	11-4	9-3
8-2	9-1*	8-2	18-4	8-4	11-4
12-2	11-2	15-2	10-4	13-4	13-4
8-2	14-2	15-2	11-4	19-4	12-4
12-2	15-2	14-2	12-4	16-4	8-4
14-2	8-2	13-2	14-4	17-4	11-4*

As stated previously, the space utilization factor (ALPHA) for regular stock was intialized at 2.0 throughout the experiments. However, an experiment was performed by varying this parameter as well. The stability results for this experiment are shown in Tables 13 and 14. It will be observed that the starting value of the space utilization factor has little affect on the stability of vendor selection.

F. Service Level Results

Service levels for the four cost profiles are shown in Table 15. Entries in the table are the means and standard deviations of the service levels for ten runs under the conditions shown. Each run was conducted for the standard horizon of 20 years. For purposes of comparison, a cell may be defined as four entries under different costs, but identical for other conditions. It will be observed that each cell defined in this manner has four closely grouped values, indicating an indifference to the different cost conditions.

The fixed beta mode entries in Table 15 can also be compared to the entries for the adaptive beta mode. This comparison shows that the service levels are consistently lower for the adaptive beta mode and the standard deviations are consistently higher for this mode. It will also be observed that although the mean service levels are lower for the adaptive beta mode, these levels are consistently greater than the desired service levels.

A third comparison can be made in Table 15 by contrasting the service levels based on demand and the service levels based on days. The service levels based on days are known to be inflated by those

TABLE 15

COMPARISON OF SERVICE LEVELS FOR DIFFERENT COSTS

FIXED BETA MODE				ADAPTIVE BETA MODE				CONDITIONS		
SERV LEV (DEMAND)		SERV LEV (DAYS)		SERV LEV (DEMAND)		SERV LEV (DAYS)				
MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD	DESIRED SERVICE LEVEL	COST PROFILE	ITEM
.985	.004	.993	.002	.940	.010	.973	.005	.90	1	1
.986	.005	.994	.002	.942	.008	.975	.004	.90	2	1
.985	.005	.994	.002	.941	.014	.972	.006	.90	3	1
.983	.005	.992	.002	.942	.008	.974	.004	.90	4	1
.991	.005	.998	.001	.958	.012	.989	.003	.90	1	2
.990	.006	.998	.001	.959	.016	.992	.008	.90	2	2
.988	.006	.997	.001	.956	.013	.991	.003	.90	3	2
.987	.006	.997	.002	.954	.011	.990	.003	.90	4	2
.990	.007	.995	.003	.960	.013	.980	.006	.95	1	1
.989	.006	.995	.003	.957	.016	.981	.007	.95	2	1
.989	.006	.995	.003	.960	.013	.979	.006	.95	3	1
.988	.004	.995	.002	.956	.008	.980	.008	.95	4	1
.995	.003	.999	.001	.968	.016	.993	.004	.95	1	2
.992	.003	.998	.001	.959	.012	.991	.003	.95	2	2
.993	.004	.998	.001	.959	.009	.989	.006	.95	3	2
.994	.006	.998	.002	.963	.017	.992	.004	.95	4	2

days when no demands are presented, since P(0) = .5488 for item 1 and P(0) = .7788 for item 2. This effect is verified by the data as the service levels based on days are universally greater than the service levels based on demands.

Table 16 illustrates the effect of A, the exponential smoothing coefficient, upon the service levels. It can be seen that the three different values of A produce essentially the same service levels. The same comparisons of modes and service level types can be made with this table as in Table 16 resulting in the same conclusions.

G. Cost Results

Cost results are summarized in Table 17. Two major conclusions are drawn from these results. First that the costs are significantly lower for the adaptive beta mode than for the fixed beta mode. Second that the variance is higher for simulation costs than the planned costs.

It will be noted that these conclusions are independent of the cost structure and values for A. Independence from the value of A is important since it could reasonably be inferred that the smaller variance of planned costs was due to exponential smoothing. Another reasonable hypothesis for the smaller variance is the use of expected values in the procurement submodel. This hypothesis is not as readily tested as the exponential smoothing and will be left untested in this thesis.

Variations of mean cost with different cost profiles are, of

TABLE 16

COMPARISON OF SERVICE LEVELS FOR DIFFERENT VALUES OF A

FIXED BETA MODE				ADAPTIVE BETA MODE				CONDITIONS		
SERV LEV (DEMAND)		SERV LEV (DAYS)		SERV LEV (DEMAND)		SERV LEV (DAYS)				
MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD	DESIRED SERVICE LEVEL	ITEM	A
.985	.004	.993	.002	.940	.010	.973	.005	.90	1	.1
.986	.005	.993	.002	.941	.012	.973	.005	.90	1	.3
.983	.005	.992	.002	.942	.008	.974	.004	.90	1	.5
.991	.005	.998	.001	.963	.013	.992	.003	.90	2	.1
.993	.004	.998	.001	.956	.015	.990	.004	.90	2	.3
.987	.006	.997	.002	.954	.011	.990	.003	.90	2	.5
.990	.007	.995	.003	.960	.013	.981	.006	.95	1	.1
.990	.007	.995	.003	.955	.015	.979	.006	.95	1	.3
.988	.004	.995	.002	.956	.016	.980	.008	.95	1	.5
.995	.003	.999	.001	.968	.016	.993	.004	.95	2	.1
.993	.005	.999	.001	.962	.016	.992	.002	.95	2	.3
.994	.006	.998	.002	.963	.018	.992	.004	.95	2	.5

TABLE 17

COST RESULTS SUMMARY

FIXED BETA MODE				ADAPTIVE BETA MODE				CONDITIONS		
PLANNED		SIMULATED		PLANNED		SIMULATED				
MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD	SERVICE LEVEL	COST PROFILE	A
5285	13.2	5217	71.0	5027	37.0	4959	76.0	.90	1	.1
5300	21.4	5239	78.5	4974	31.1	4981	85.1	.90	2	.1
5255	21.9	5240	68.5	4937	32.2	4938	84.2	.90	3	.1
5353	25.3	5347	63.0	5010	39.6	5014	81.5	.90	4	.1
5322	16.5	5325	74.8	5051	56.4	5068	105.1	.95	1	.1
5360	16.9	5357	72.9	5054	57.3	5058	123.7	.95	2	.1
5359	17.3	5351	65.7	5026	66.1	5027	116.9	.95	3	.1
5475	22.1	5453	70.8	5131	78.5	5139	98.5	.95	4	.1
5221	25.4	5225	70.0	4985	37.6	4975	102.5	.90	2	.3
5234	19.6	5210	74.4	4988	40.7	4978	84.9	.90	2	.5
5338	23.1	5295	72.5	5045	62.2	5017	96.2	.95	2	.3
5339	17.6	5319	82.7	5074	74.7	5046	98.3	.95	2	.5

course, to be expected. It is interesting to note that the unit cost change (cost profile 4) has a greater effect than setup cost changes (cost profiles 1, 2, and 3).

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FURTHER STUDY

A. Summary

An adaptive model for an integrated procurement-inventory system has been developed in this thesis. The model is composed of a procurement planning submodel which provides a minimum cost policy consistent with a level of service, and a simulation submodel which tests the policy and provides information for the procurement submodel to formulate the next year's policy. The model has been applied to a system where the initial knowledge of the vendor's lead time distribution consists of estimates of the average lead time and the demand is Poisson distributed with known parameters. The lead time estimates must be obtained from the vendor and consequently may be biased towards shorter times which would attract more business in a competitive market. In the simulation, lead times are generated from the normal and gamma distributions.

An experiment was performed which examined the model's ability to provide the desired service level during the initial year when minimum lead time information was available. The desired service level was furnished the majority of the time and a high percentage of the observed service levels were close to the desired level. It was shown that a greater probability of providing the desired service level could be obtained by inflating the service level figure supplied to the model. The results of this experiment are evidence that a reasonable service level will be maintained even with minimum lead time information.

Two modes of operating the model have been developed by defining an effective service level which is utilized in the procurement planning submodel. In the fixed beta mode, the effective service level is the same as the service level input to the model. In the adaptive beta mode, the effective service level is modified as information is gained in the simulation. The mean of both service levels and total costs were found to be greater in the fixed beta mode, while the variance of service levels and total costs were greater for the adaptive beta mode. The mean service levels for both modes were consistently greater than the desired service level.

The modes of operation furnish flexibility to the decision maker. For example, he may choose a lower cost if he is indifferent to greater variance in service levels and cost, or a higher cost if his operation is hampered by variability.

The length of the horizon required for stability, indicating sufficient collection of lead time information, has been defined by consistent selection of the same vendor. An investigation was performed under several different conditions and it was determined that period required for stability and the vendor selected is most sensitive to the relative unit costs, the desired service level and the mode of operating the model. An overall summary is that stability was achieved in every case for item 1 and 90.3 of the cases for item 2. Thus it is concluded that stability will usually occur under the criteria chosen.

The expected total cost is calculated by the procurement planning submodel and total cost data is also collected in the simulation. The difference in the means of these costs for multiple runs with different seeds was less than 1.5 percent for all experiments. However, the variances were greater in every case for the simulated costs. This comparison indicates that the expected costs for the procurement policy will be realized in the long run, but a higher variation in actual costs will occur than shown by the variance in the planned costs. The simulation data provided by the model should be an effective tool for estimating the amount of variance that would be encountered. Variation in costs may be an important consideration since this is one element in the risk of operating a business.

B. Conclusions

The model has been applied to a system in a particular stochastic environment and the characteristics of vendor selection, service level and annual cost have been examined. The initial discrete distributions of lead time and demand input to the procurement planning submodel and the distributions used to generate lead times and demands in the simulation submodel were chosen to pose an interesting problem for investigation. However, the model is not limited by these choices and may be applied to investigate similar systems in other stochastic environments. With a slight change, simulation data could be used to update the discrete distributions of demand as well as the distributions of lead time. Thus situations with initially incomplete information on the distribution of demand could also be explored.

The model would be useful to the manager or systems analyst for evaluating the effects of changes in the environment or alternatives upon the procurement policy over the desired planning horizon. A few of the possible applications are:

1. Changes in internal or vendor costs.
2. Changes in the distributions of demands and/or lead times.
3. Alternative management policies on service levels.
4. Introduction of new vendors.

The model provides the following information which would be useful in evaluating the effects of changes or alternatives.

1. The vendor, reorder point, reorder quantity and safety stock corresponding to the minimum expected annual cost.
2. A breakdown of the expected annual cost and data to estimate the variance of these costs.
3. Expected service levels and data to estimate the variance of service levels.
4. Means to estimate the period required to achieve a stable procurement policy when information on the stochastic environment is incomplete.

C. Recommendations for Further Study

In many circumstances the demand may be seasonal or contain a trend. Little modification of the model would be required to include these effects and a detailed investigation would be worthwhile. Other interesting investigations could be performed by assuming either a fixed limit on warehouse size rather than an overstock cost or limitations on the capacity of the vendors to supply the required amounts.

Application of the model to large systems is restricted due to large core requirements and execution times. A possible solution to these limitations is development of a method to decompose the system into an equivalent set of subsystems and an algorithm that utilizes dominant relations to reduce the number of combinations that must be considered.

APPENDIX A

GENERATION OF DEVIATES

The operating system of the PDP-10 computer used in this thesis was provided with a library of the Scientific Subroutine Package designed for the IBM-360.[10] The following subroutines from the library were utilized in the submodel:

Randu - Random number generator modified for use on a machine with a 36-bit word length.

Gauss - Generator of normal deviates.

Subroutines for generation of deviates from the Poisson and gamma distributions were not available in the library. These subroutines were adapted from Naylor et al.[11] Adaption consisted of recoding two instructions to permit the use of Randu instead of the random number generator provided in the reference.

APPENDIX B

EXAMPLES OF OUTPUT DATA TABLES

TABLE B2

PROCUREMENT AND SIMULATION DATA FOR ITEM 1
RUN NUMBER 10

	*.PROCUREMENT	PLAN.			*..SIMULATION	DATA..		*.SERVICE	LEVEL
YR	*VEND	ROP	QORD	SS	*DEMAND	BKORD	STKOUT	*DEMAND	DAYS
1	* 2	14	28	5	* 174	40	31	* 0.770	0.876
2	* 1	14	30	5	* 159	1	1	* 0.994	0.996
3	* 1	16	30	5	* 154	0	0	* 1.000	1.000
4	* 1	15	30	5	* 129	0	0	* 1.000	1.000
5	* 1	14	29	4	* 154	0	0	* 1.000	1.000
6	* 1	14	29	4	* 156	2	1	* 0.987	0.996
7	* 1	13	29	3	* 135	0	0	* 1.000	1.000
8	* 2	21	28	5	* 148	0	0	* 1.000	1.000
9	* 2	15	28	1	* 164	22	15	* 0.866	0.940
10	* 2	14	24	1	* 169	14	13	* 0.917	0.948
11	* 2	14	27	1	* 149	0	0	* 1.000	1.000
12	* 2	13	27	1	* 148	26	18	* 0.824	0.928
13	* 2	13	27	1	* 147	26	17	* 0.823	0.932
14	* 2	14	27	1	* 141	0	0	* 1.000	1.000
15	* 2	14	27	1	* 159	18	13	* 0.887	0.948
16	* 2	13	27	1	* 153	13	11	* 0.915	0.956
17	* 2	13	23	1	* 143	9	8	* 0.937	0.968
18	* 2	13	23	1	* 160	10	9	* 0.938	0.964
19	* 2	13	23	1	* 140	8	7	* 0.943	0.972
20	* 2	13	26	1	* 151	9	6	* 0.940	0.976

TOTAL DEMAND = 3033
TOTAL UNITS BACK ORDERED = 198
TOTAL DAYS SERVICE NOT MET = 150
BETA DEMAND = 0.935
BETA DAYS = 0.970
SEED = 920586078

TABLE B1

COMPARATIVE DATA RUN NO. 10

YR	TOTAL COST		SPACE FACTOR		PEAK FACTOR		EFF SER LEV	
	PLANNED	SIMULATED	REG.	SS.	ITEM 1	ITEM 2	ITEM 1	ITEM 2
1	5071.	5730.	2.00	1.00	1.00	1.00	.900	.900
2	5160.	5000.	2.05	1.02	0.97	0.98	.900	.850
3	5099.	5304.	2.06	1.02	0.99	0.92	.900	.779
4	5097.	5244.	2.01	1.02	0.99	0.92	.892	.671
5	5065.	5158.	1.98	1.02	0.98	0.93	.871	.671
6	5079.	5004.	1.95	1.02	1.00	0.91	.834	.671
7	5031.	5034.	1.94	1.02	1.00	0.86	.774	.671
8	5004.	4962.	1.92	1.02	1.00	0.84	.681	.671
9	4898.	5272.	1.88	1.02	1.00	0.89	.539	.671
10	4899.	5444.	1.86	1.03	0.95	0.88	.539	.671
11	4903.	4801.	1.84	1.03	0.97	0.86	.539	.671
12	4919.	4579.	1.80	1.03	0.97	0.85	.539	.671
13	4885.	4427.	1.84	1.04	0.92	0.83	.539	.671
14	4885.	5159.	1.83	1.05	0.93	0.82	.539	.671
15	4891.	4993.	1.81	1.04	0.92	0.81	.539	.671
16	4856.	4487.	1.81	1.05	0.91	0.80	.539	.529
17	4875.	4562.	1.78	1.05	0.92	0.79	.539	.529
18	4880.	4954.	1.78	1.05	0.91	0.81	.539	.529
19	4875.	4658.	1.78	1.05	0.91	0.81	.539	.529
20	4866.	4949.	1.77	1.06	0.90	0.79	.539	.529
AV	4962.	4986.	1.88	1.03	0.96	0.87	.661	.662

TABLE B3

PROCUREMENT AND SIMULATION DATA FOR ITEM 2
RUN NUMBER 10

	*	.PROCUREMENT		PLAN.		*	..SIMULATION		DATA..	*	.SERVICE	LEVEL
YR	*	VEND	ROP	QORD	SS	*	DEMAND	BKORD	STKOUT	*	DEMAND	DAYS
1	*	4	7	16	3	*	65	0	0	*	1.000	1.000
2	*	4	6	16	3	*	59	1	1	*	0.983	0.996
3	*	4	7	14	2	*	53	0	0	*	1.000	1.000
4	*	4	6	14	1	*	67	2	2	*	0.970	0.992
5	*	4	6	15	1	*	60	0	0	*	1.000	1.000
6	*	4	6	15	1	*	74	8	6	*	0.892	0.976
7	*	4	6	15	1	*	71	4	4	*	0.944	0.984
8	*	2	5	15	1	*	55	5	4	*	0.909	0.984
9	*	2	7	15	1	*	72	3	3	*	0.958	0.988
10	*	2	6	16	1	*	64	0	0	*	1.000	1.000
11	*	2	6	16	1	*	63	3	3	*	0.952	0.988
12	*	2	6	16	1	*	49	8	7	*	0.837	0.972
13	*	2	7	16	1	*	52	1	1	*	0.981	0.996
14	*	2	7	16	1	*	53	5	4	*	0.906	0.984
15	*	4	7	14	2	*	65	1	1	*	0.985	0.996
16	*	4	6	14	1	*	40	0	0	*	1.000	1.000
17	*	4	6	14	1	*	57	3	3	*	0.947	0.988
18	*	4	6	14	1	*	59	6	6	*	0.898	0.976
19	*	4	6	14	1	*	70	12	9	*	0.829	0.964
20	*	4	6	14	1	*	61	1	1	*	0.984	0.996

TOTAL DEMAND = 1209
TOTAL UNITS BACK ORDERED = 63
TOTAL DAYS SERVICE NOT MET = 155
BETA DEMAND = 0.948
BETA DAYS = 0.989
SEED = 920586078

TABLE B4

PLANNED COST BREAKDOWN FOR ITEM 1   RUN NUMBER   10

					..REGULAR STOCK..			...SAFETY STOCK..*		
YR	PURCH	ORDER	STKOUT	OVERSTK*	CAPITAL	HAND	RENT*	CAPITAL	HAND	RENT*
1	2250.00	321.43	3.01	267.86*	52.50	281.	557.*	18.75	67.	150.*
2	2325.00	350.00	3.11	242.86*	58.12	282.	581.*	19.37	63.	147.*
3	2325.00	350.00	3.10	248.57*	58.12	286.	579.*	19.37	49.	146.*
4	2325.00	350.00	4.04	248.71*	58.12	285.	592.*	19.37	54.	147.*
5	2325.00	362.07	5.92	252.25*	56.19	289.	583.*	15.50	40.	118.*
6	2325.00	362.07	4.95	258.06*	56.19	289.	593.*	15.50	38.	118.*
7	2325.00	362.07	6.12	258.12*	56.19	293.	595.*	11.62	24.	88.*
8	2250.00	321.43	14.59	267.39*	52.50	290.	579.*	7.50	34.	147.*
9	2250.00	321.43	19.12	267.43*	52.50	298.	593.*	3.75	7.	29.*
10	2250.00	375.00	21.28	296.43*	45.00	298.	514.*	3.75	8.	29.*
11	2250.00	333.33	17.91	268.89*	50.63	298.	585.*	3.75	7.	29.*
12	2250.00	333.33	18.09	269.78*	50.63	298.	595.*	3.75	8.	29.*
13	2250.00	333.33	19.28	256.69*	50.63	297.	584.*	3.75	9.	29.*
14	2250.00	333.33	16.66	258.80*	50.63	298.	587.*	3.75	8.	29.*
15	2250.00	333.33	17.16	256.07*	50.63	298.	595.*	3.75	8.	29.*
16	2250.00	333.33	19.22	253.61*	50.63	298.	593.*	3.75	9.	29.*
17	2250.00	391.30	19.45	300.55*	43.12	297.	513.*	3.75	9.	29.*
18	2250.00	391.30	20.09	297.67*	43.12	297.	514.*	3.75	10.	29.*
19	2250.00	391.30	19.70	295.85*	43.12	297.	513.*	3.75	10.	28.*
20	2250.00	346.15	19.33	259.58*	48.75	297.	584.*	3.75	9.	28.*
AV	2272.50	349.78	13.61	266.26*	51.37	293.	571.*	8.60	23.	70.*

TABLE B5

SIMULATION COST BREAKDOWN FOR ITEM 1 RUN NUMBER 10

					..REGULAR STOCK..			...SAFETY STOCK..*		
YR	PURCH	ORDER	STKOUT	OVERSTK*	CAPITAL	HAND	RENT*	CAPITAL	HAND	RENT*
1	2940.00	420.00	0.00	250.00*	27.85	216.	295.*	13.66	168.	109.*
2	2325.00	350.00	0.00	300.00*	58.57	313.	601.*	18.91	80.	146.*
3	2325.00	350.00	0.00	250.00*	75.70	302.	777.*	19.36	7.	150.*
4	2325.00	350.00	0.00	200.00*	69.05	249.	708.*	19.37	0.	150.*
5	2247.50	350.00	0.00	300.00*	68.94	323.	707.*	15.33	21.	119.*
6	2247.50	350.00	0.00	250.00*	61.61	289.	632.*	15.11	28.	117.*
7	2247.50	350.00	0.00	250.00*	65.56	277.	673.*	11.61	11.	90.*
8	2100.00	300.00	0.00	250.00*	79.31	288.	841.*	18.75	0.	150.*
9	2520.00	360.00	0.00	150.00*	61.38	258.	651.*	3.30	11.	26.*
10	2520.00	420.00	0.00	400.00*	54.21	332.	575.*	3.30	18.	26.*
11	2025.00	300.00	0.00	250.00*	74.91	282.	794.*	3.75	7.	30.*
12	2430.00	360.00	0.00	150.00*	45.49	223.	482.*	3.21	32.	26.*
13	2025.00	300.00	0.00	250.00*	59.98	254.	636.*	3.24	11.	26.*
14	2430.00	360.00	0.00	250.00*	67.85	276.	719.*	3.75	0.	30.*
15	2430.00	360.00	0.00	250.00*	57.63	282.	611.*	3.30	11.	26.*
16	2025.00	300.00	0.00	250.00*	61.24	285.	649.*	3.42	14.	27.*
17	2070.00	360.00	0.00	250.00*	45.36	259.	481.*	3.41	21.	27.*
18	2415.00	420.00	0.00	300.00*	46.36	276.	491.*	3.43	28.	27.*
19	2070.00	360.00	0.00	250.00*	54.90	275.	582.*	3.50	21.	28.*
20	2340.00	360.00	0.00	300.00*	51.14	284.	542.*	3.56	18.	28.*
AV	2302.87	354.00	0.00	255.00*	59.35	277.	622.*	8.66	25.	68.*

TABLE B6

PLANNED COST BREAKDOWN FOR ITEM 2   RUN NUMBER   10

					..REGULAR STOCK..			...SAFETY STOCK..*		
YR	PURCH	ORDER	STKOUT	OVERSTK*	CAPITAL	HAND	RENT*	CAPITAL	HAND	RENT*
1	250.00	97.66	0.57	195.31*	8.00	119.	318.*	3.00	21.	90.*
2	250.00	97.66	0.39	191.41*	8.00	119.	310.*	3.00	21.	88.*
3	250.00	111.61	1.75	204.32*	7.00	123.	270.*	2.00	7.	59.*
4	250.00	111.61	2.07	206.21*	7.00	123.	276.*	1.00	7.	29.*
5	250.00	104.17	1.89	194.05*	7.50	123.	301.*	1.00	7.	29.*
6	250.00	104.17	1.66	190.27*	7.50	123.	307.*	1.00	7.	29.*
7	250.00	104.17	1.94	179.57*	7.50	123.	308.*	1.00	7.	29.*
8	218.75	166.67	0.84	174.12*	6.56	122.	310.*	1.75	9.	29.*
9	218.75	166.67	1.69	184.48*	6.56	123.	318.*	1.75	7.	29.*
10	218.75	156.25	1.47	171.28*	7.00	123.	343.*	1.75	7.	29.*
11	218.75	156.25	1.31	168.80*	7.00	123.	347.*	1.75	7.	29.*
12	218.75	156.25	1.78	166.57*	7.00	123.	353.*	1.75	7.	29.*
13	218.75	156.25	1.96	162.93*	7.00	124.	346.*	1.75	5.	29.*
14	218.75	156.25	2.70	159.66*	7.00	124.	348.*	1.75	5.	29.*
15	250.00	111.61	1.25	180.96*	7.00	122.	308.*	2.00	11.	57.*
16	250.00	111.61	1.38	179.61*	7.00	123.	308.*	1.00	8.	29.*
17	250.00	111.61	1.29	176.53*	7.00	123.	312.*	1.00	8.	29.*
18	250.00	111.61	1.25	181.20*	7.00	123.	313.*	1.00	8.	29.*
19	250.00	111.61	1.35	179.82*	7.00	123.	312.*	1.00	8.	28.*
20	250.00	111.61	1.40	175.23*	7.00	123.	315.*	1.00	8.	28.*
AV	239.06	125.76	1.50	181.12*	7.13	123.	316.*	1.56	9.	38.*

TABLE B7

SIMULATION COST BREAKDOWN FOR ITEM 2 RUN NUMBER 10

					*..REGULAR	STOCK..	*...	SAFETY	STOCK..	*
YR	PURCH	ORDER	STKOUT	OVERSTK*	CAPITAL	HAND	RENT*	CAPITAL	HAND	RENT*
1	320.00	125.00	0.00	200.00*	9.99	145.	397.*	3.00	0.	90.*
2	192.00	75.00	0.00	50.00*	6.38	88.	254.*	2.64	59.	79.*
3	224.00	100.00	0.00	200.00*	8.35	103.	332.*	1.96	21.	59.*
4	280.00	125.00	0.00	250.00*	8.53	130.	339.*	0.98	11.	29.*
5	240.00	100.00	0.00	150.00*	8.98	120.	357.*	1.00	0.	30.*
6	300.00	125.00	0.00	100.00*	7.86	130.	312.*	0.90	11.	27.*
7	300.00	125.00	0.00	150.00*	7.70	117.	306.*	0.94	24.	28.*
8	157.50	120.00	0.00	200.00*	6.80	101.	309.*	0.77	14.	26.*
9	262.50	200.00	0.00	200.00*	8.35	138.	380.*	0.84	14.	29.*
10	224.00	160.00	0.00	150.00*	8.57	126.	389.*	0.88	7.	30.*
11	224.00	160.00	0.00	150.00*	7.31	117.	332.*	0.84	14.	29.*
12	168.00	120.00	0.00	100.00*	7.01	79.	318.*	0.80	7.	27.*
13	168.00	120.00	0.00	100.00*	7.36	96.	334.*	0.83	7.	29.*
14	224.00	160.00	0.00	150.00*	7.82	89.	355.*	0.83	7.	29.*
15	224.00	100.00	0.00	150.00*	6.82	129.	271.*	1.94	21.	58.*
16	168.00	75.00	0.00	100.00*	10.20	82.	406.*	1.00	0.	30.*
17	224.00	100.00	0.00	200.00*	9.33	105.	371.*	0.94	7.	28.*
18	224.00	100.00	0.00	150.00*	8.00	97.	318.*	0.91	21.	27.*
19	280.00	125.00	0.00	150.00*	7.72	103.	307.*	0.89	14.	27.*
20	280.00	125.00	0.00	100.00*	8.81	124.	350.*	0.98	4.	30.*
AV	234.20	122.00	0.00	150.00*	8.09	111.	337.*	1.19	13.	37.*

TABLE B8

MISCELLANEOUS DATA RUN NO. 10

YR	NO. ORDER CROSSES ITEM 1	NO. ORDER CROSSES ITEM 2	NO. REORDER PT. OVERSHOOTS BY 1 UNIT ITEM 1	BY 1 UNIT ITEM 2	BY 2 UNITS ITEM 1	BY 2 UNITS ITEM 2	BY 3 UNITS ITEM 1	BY 3 UNITS ITEM 2
1	0	0	1	0	2	1	0	0
2	0	0	0	0	0	0	0	0
3	0	0	2	0	0	0	0	0
4	0	0	3	1	0	0	0	0
5	0	0	3	0	1	0	0	0
6	0	0	1	1	1	0	0	0
7	0	0	1	0	2	0	0	1
8	0	0	1	0	1	0	0	0
9	0	0	2	1	1	0	0	0
10	0	0	2	0	0	0	0	0
11	0	0	0	1	0	0	0	0
12	0	0	3	1	0	0	0	0
13	1	0	2	0	0	0	0	0
14	0	0	3	0	1	0	0	0
15	0	0	4	1	1	0	0	0
16	0	0	1	0	1	0	0	0
17	0	0	2	1	1	0	0	0
18	0	0	4	0	1	0	0	0
19	0	0	2	2	0	0	0	0
20	0	0	2	1	0	0	1	0

APPENDIX C

COST PROFILES

Costs Fixed in Each Profile

Annual rental per pallet of regular stock	= 39.75
Annual rental per pallet of safety stock	= 30.00
Fixed internal cost to place an order	= 25.00
Handling cost to store or withdraw a pallet of regular stock	= 3.50
Handling cost to store or withdraw a pallet of safety stock	= 1.00
Overstock cost	= 50.00
Rate of return on investment	= .25

COST PROFILE 1

Item 1

MOQ	Cost/1000 Units	Vendor Setup Cost
500	155.00	45.00
500	150.00	45.00
0	175.00	25.00
0	170.00	25.00

Item 2

MOQ	Cost/1000 Units	Vendor Setup Cost
250	75.00	30.00
250	70.00	25.00
0	85.00	15.00
0	80.00	15.00

NOTE: MOQ is in units.

Item 1 = 100 units/pallet.

Item 2 = 50 units/pallet.

COST PROFILE 2

Item 1

MOQ	Cost/1000 Units	Vendor Setup Cost
500	155.00	50.00
500	150.00	40.00
0	175.00	30.00
0	170.00	20.00

Item 2

MOQ	Cost/1000 Units	Vendor Setup Cost
250	75.00	30.00
250	70.00	20.00
0	85.00	15.00
0	80.00	5.00

NOTE: MOQ is in units.

Item 1 = 100 units/pallet.

Item 2 = 50 units/pallet.

COST PROFILE 3

Item 1

MOQ	Cost/1000 Units	Vendor Setup Cost
500	155.00	50.00
500	150.00	45.00
0	175.00	30.00
0	170.00	25.00

Item 2

MOQ	Cost/1000 Units	Vendor Setup Cost
250	75.00	30.00
250	70.00	25.00
0	85.00	15.00
0	80.00	10.00

NOTE: MOQ is in units.

Item 1 = 100 units/pallet.

Item 2 = 50 units/pallet.

COST PROFILE 4

Item 1

MOQ	Cost/1000 Units	Vendor Setup Cost
500	160.00	50.00
500	150.00	45.00
0	180.00	30.00
0	170.00	25.00

Item 2

MOQ	Cost/1000 Units	Vendor Setup Cost
250	80.00	30.00
250	70.00	25.00
0	100.00	15.00
0	90.00	10.00

NOTE: MOQ is in units.

Item 1 = 100 units/pallet.

Item 2 = 50 units/pallet.

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American University Washington, D.C. B.S., Dist. Sciences (Physics)	Graduated 1969
Lehigh University Bethlehem, Pennsylvania Candidate for M.S. in Industrial Engineering	1971-1973

WORK EXPERIENCE:

U. S. Navy Aviation Electronics Technician	1954-1959
American Telephone & Telegraph Operations Supervisor	1963-1969
Western Electric Co., Inc. Planning Engineer-Technical Writing Specialist	1969-1971
Melpar, Inc. Test Technician	1959-1961